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DEFENSE DEPENDENCE ON FOREIGN HIGH TECHNOLOGY:

AN ASSESSMENT OF U.S. VULNERABILITY

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TABLE OF CONTENTS

CHAPTER I
INTRODUCTION AND OVERVIEW

A. THIS REPORT

Numerous recent studies and analyses have investigated the causes of industrial base migration and its effect on the U.S. technology and manufacturing bases, and potentially, on Defense capability. (Summaries of some of these have been included in Appendix B.) DARPA undertook this study in an effort to supplement the considerable and valuable "conventional wisdom" produced by the previous reports by commissioning contractor studies to:

- examine parts lists of selected weapons systems in greater depth than previously, to whatever subtier contractor level would reveal the ultimate national origin of their components and of the equipment and assembly, packaging, and testing services used in their production;

- assess the degree of vulnerability resulting from any dependence discovered; and

- examine the likelihood that foreign suppliers might seek to use those vulnerabilities to pressure the U.S. in peacetime, by reviewing cases where technology denial has been used in the past to exert political leverage.

Although a study of this nature should involve examination of as many weapons systems/subsystems as possible, in order to develop a comprehensive picture of the scope of the problem at hand, this study has been limited to a representative sampling (although that sampling was carefully chosen, as delineated in Chapter II). As has been pointed out in several other studies, cited in our bibliography, one of the major obstacles to development of solutions to the problem of DoD's vulnerability in this matter,. and even worse, to realization of the extent of the problem itself, is a lack of readily accessible information regarding sources of devices and components of weapons systems at the sub-tier level. Gathering and compilation of data represented the most time-consuming aspects of this study.

In setting the context of this study, foreign vulnerability was viewed as a subset of foreign dependency, which in turn was viewed as a subset of foreign sourcing (illustrated in Figure I.1) although that definition became less distinct as our interpretation of the problem evolved. Such a definition "fits" when one is discussing product sourcing; as one considers that processes, and indeed, intellectual property may be sourced as well, the notion of vulnerability becomes more fluid, and

potential vulnerabilities become more of a concern than existing threats that may be countered by a single design change or by stockpiling a single product.

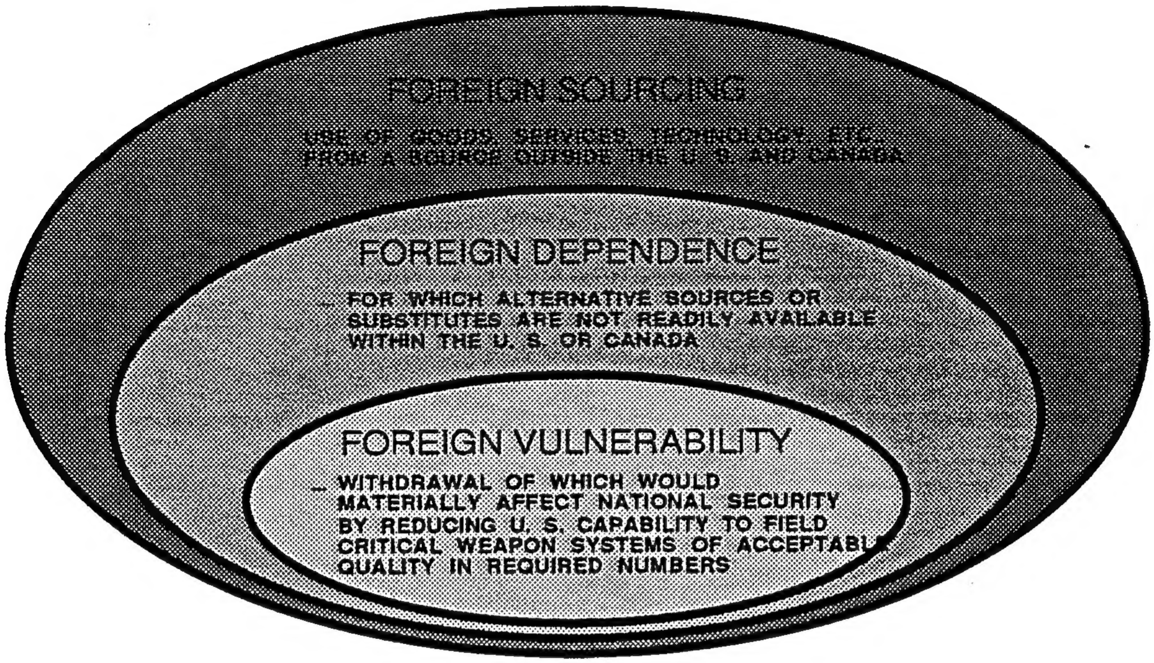

Figure I.1
DEFINITIONS[1]

The scenario envisioned was a peacetime scenario rather than one involving surge/mobilization capabilities. The potential "threat" involved in foreign sourcing was viewed in terms of a continuum, or range, where foreign-owned, foreign-controlled, offshore locations represent one extreme; U.S.-owned, U.S.-controlled, and U.S. located represent the other; and the various possible additional permutations (for example, foreign-owned, U.S. location/U.S.-owned, foreign location) represent less obvious potential for disruption of U.S. national security measures. Again, it quickly became apparent that in view of the growing globalization of the industrial base, the distinction between U.S. companies with foreign subsidiaries and foreign companies with U.S. subsidiaries was hazy at best in terms of potential dangers to supply, and that growing mutual dependence forms a security of a new sort, but involves dangers of a new sort as well.

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1 Libicki *et al.*

B. BACKGROUND

Throughout history, the ability to maintain a high degree of domestic self-sufficiency in production of armaments has been recognized as a principal aspect of national sovereignty. America's first experience with the risks of dependence on foreign production sources occurred during the Revolutionary War. Having virtually no domestic industries, the new nation was forced to rely on foreign suppliers, principally French and Dutch, for essentially all munitions needed to sustain the conflict. America's ability to continue its struggle for national survival frequently hinged on the political and economic decisions of European powers who had little natural sympathy for U.S. objectives.

What could be considered the first recommendation for a U.S. "industrial policy," Alexander Hamilton's 1791 "Report on Manufacturers," was intended to develop a domestic manufacturing base that could ensure the U.S. basic self-sufficiency in arms production, avoiding the danger of control by hostile European powers that dependence implied. Echoing this suggestion, Secretary of War Henry Knox requested funds to establish national armories. While conceding that domestically produced weapons might be more expensive than imports, he argued that the extra price was little to pay "compared with the solid advantages that would result from extending and perfecting the means upon which our safety may ultimately depend."[2]

At the end of World War II and for a number of years thereafter, the United States was the unchallenged military and industrial leader of the world. American industry had been strong before the war, and every other major combatant (Britain, Russia, France, Germany, and Japan) experienced significant combat or bombing damage to its critical industries and supporting infrastructure.

The defense industry continued to be a major driver of U.S. technological progress after the war, as it had been throughout U.S. history up to then. As a principal developer of new technologies, the Department of Defense had access to the latest, state-of-the-art products and manufacturing processes.

Facing severely constrained defense funding immediately after the Korean conflict, the U.S. adopted a policy of using weapons with superior performance and quality to offset acknowledged inferiority in numbers of troops and systems. This policy is still in place today.

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2 James A. Huston, "The Sinews of War: Army Logistics 1775-1953, Washington, Chief of Military History," 1966, p. 93.

In the past two decades, U.S. leadership in high-technology industry has diminished. The U.S. has lost or soon will lose the lead in several important emerging technologies.[3] In those areas, the Department of Defense will be forced to rely on foreign sources for high technology if it is to maintain America's traditional technological edge.

C. VARIETIES OF FOREIGN DEPENDENCE

Three distinct types of foreign dependence warrant the attention of the Federal Government. Traditionally, concern has focused on dependence on foreign sources for products (materials, components, subassemblies, or end items), since interruption of supply has a major and immediate impact on operational readiness. A 1986 survey of several critical weapons systems (performed for the Joint Logistics Commanders, JLC) showed extensive foreign sourcing and some foreign dependence in every program examined.[4] It showed how a disruption in the supply of foreign-sourced components could halt production of such key weapons systems as the F-16 and F/A-18 aircraft, the M-1 tank, sonobuoys, and the Sidewinder missile for a period of months.

This primary dependence issue is addressed in Chapter II of this study, in a report prepared by the Institute for Defense Analyses (IDA). Several representative weapons systems were examined for foreign sourcing, down to the subtier level. In addition to determining sources of product origin, the study team also extended its review to examine sources of production equipment used to make the systems, products, or devices, and sources of packaging, testing, and assembly services.

The Department of Defense must also be concerned about foreign sourcing of the processes and equipment required to produce its weapons systems and with the advanced technologies that it may require in the future. These manufacturing processes and advanced technologies may or may not be related to products that are currently purchased by the Department of Defense.

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3 See, for example, Defense Science Board, "Report of the Defense Science Board Task Force on Semiconductor Dependency," Washington OUSD(A), 1987; Mobilization Concepts Development Center, "U.S. Industrial Base Dependence/Vulnerability," Washington, National Defense University, 1986 and 1987; OUSD(A), "Bolstering Defense Industrial Competitiveness," Washington, 1988; Air Force Association and USNI Military Database, "Lifeline in Danger: An Assessment of the United States Defense Industrial Base," Washington, Aerospace Education Foundation, 1988; Department of Defense, "Critical Technologies Plan," Washington, Government Printing Office, 1989; and Department of Defense, "Soviet Military Power: Prospects for Change," 1989, p. 137.

4 Applied Concepts Corporation and The Analytic Sciences Corporation, "A Study of the Effect of Foreign Dependency," Arlington, Virginia, 1986.

The Defense Department's report on "Bolstering Defense Industrial Competitiveness" identified numerically controlled machine tools and electronics manufacturing equipment as "the leading edge of scores of technologies where other nations are developing the most advanced manufacturing technologies for the most advanced products." The report concluded that:

> As long as state-of-the-art production equipment is manufactured in the United States, there is a substantial capability to reconstitute or expand American product industries. However, without the basic tools for manufacturing, this capability virtually disappears, leaving United States security vulnerable to the political and economic processes of other nations.[5]

These issues are addressed in Chapter III, in a study performed by The Analytic Sciences Corporation (TASC). Based on earlier TASC studies and the IDA findings, the study concludes that many important vulnerabilities are found in the processing arena, and carefully examines three key industrial vulnerabilities.

Chapter IV, prepared by Science Applications International Corporation, examines the likelihood that suppliers upon whom the U.S. depends in areas of high technology would attempt to exploit that dependence. The study examines historical examples of occasions when technology denial was used by supplier nations to apply political leverage to the recipients.

A third form of dependence involves advanced technologies which will be embodied in future products or processes required by the Department of Defense. Technology is the application of knowledge to achieve scientific, industrial or commercial objectives, and the methods and materials used to achieve them, rather than a product that can be purchased directly. The issue of technology dependence does not neatly fit the product-oriented definition of a foreign dependence. Nevertheless, we are subject to a high degree of foreign competition in many technologies.

Considerable attention has been given to identifying technologies that are critical to defense where dependence might be deemed more of a threat to national security. A Congressionally imposed requirement (contained in the FY89 Authorization Act) led to the development of a Defense Department "Critical Technologies Plan." The plan identifies 22 technologies that are considered critical to maintaining U.S. battlefield superiority into the 21st Century, describes ongoing

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5 Under Secretary of Defense (Acquisition), "Bolstering Defense Industrial Competitiveness," 1988, p. 31.

worldwide developments in each of these areas, and evaluates U.S. competitiveness in each of these areas compared to other nations.

Of 21 technologies evaluated in the May 1989 version of the "Critical Technologies Plan" (no net assessment was made for "signature control"), Japan was considered to have a "significant lead" in development of six and was considered capable of making "major contributions" in two others. NATO allies were not considered clearly ahead in any, but were capable of "major contributions" in five areas. The Soviet Union was considered to have a significant lead on the West in two areas and generally on a par in two others.

Areas of technological parity or inferiority may represent the greatest long term threat to the U.S. capability to field critical weapons systems of acceptable quality in required number.

CHAPTER II
FOREIGN SOURCING IN REPRESENTATIVE WEAPON SYSTEMS

A. INTRODUCTION

The Institute for Defense Analyses (IDA) examined selected subsystems of major U.S. weapon systems to determine and quantify the extent of their dependence on foreign technology. The four classes of systems chosen for study were: cockpit displays, aircraft radars, air-to-air missiles, and heavy combat vehicle engines. The criteria that led to selection of these subsystems were intended to assure broad representation of widely used system types containing important emerging technologies (preferably dual use technologies), fielded by each of the Services. Evolving multi-generation systems (including at least one major recent upgrade each) were chosen, to determine if newer versions tend to be more dependent on foreign technology.

B. METHODOLOGY

IDA study teams familiar with the systems and services involved wrote to and then visited the Program Offices responsible for the subsystems to be examined. Then, with the approval of the Program Offices, they made an extensive series of visits to prime and subtier contractors, using a systematic approach to elicit as much information as possible about *sourcing*, including the reasoning process followed by purchasing agents and others who considered foreign sourcing for key components. (The approach attempted to avoid having the replies colored by avoiding references to *dependence* or *vulnerability*.) As much information as possible was gathered from the purchasing agents—many of whom were very knowledgeable in this area—about the existence and performance of domestic and foreign competitors to the sources finally selected. In many cases, the offices visited provided additional information after the visits.

The case studies in the Annexes present key information gathered during these visits and the visiting teams' analyses of the information (which benefited from the teams' own development experience and from a considerable degree of cross-fertilization between visits and study teams).

C. KEY FINDINGS

The following is a summary of key findings of the four studies. A more detailed description of the results of the individual weapon systems studies are included in Annexes I through IV to this chapter.

1. General

- Dependence on foreign technology was found in every system and system upgrade studied.

- Heavy foreign dependence on a few *highly concentrated foreign sources* (Japan and West Germany) was found in four technologies: micro-electronics, specialty materials, production equipment, and high resolution displays. These were once well established in the U.S. by merchant industries, but were lost as offshore producers gained cost and volume advantages.

- The defense systems are heavily dependent on a single Japanese source for ceramic packaging.

- Estimates for the development of a domestic source of production ranged from three to six years for specialty materials such as ferrite, optical, and filter glass, to between six months and three years for the development of alternative sources in other mature technology items where foreign sourcing is dominant but more diversified.

- The IDA study revealed high and growing dependence on foreign sources of machine tools. While a diversity of foreign sources remains, some types of equipment, particularly numerically controlled machine tools, show a growing reliance on Japanese sources. The reasons given have mainly to do with cost, quality, features, delivery, reliability, and support advantages; further study would be required to assess to what extent technology advantages are a factor.

- U.S. manufacturers struggle to maintain a viable share of the world market in CRT displays from their few remaining onshore facilities. In emerging flat panel liquid crystal display technologies, the U.S. commercial manufacturing base is limited. Advanced manufacturing capability for flat panel displays resides almost exclusively offshore.

- Factors found to be influencing dependence on foreign technologies: (1) losses of U.S. capabilities to foreign producers with lower costs, better product, service and support advantages, and management skills; (2) lack of interest or capabilities by U.S. suppliers; (3) DoD procurement requirements and costs causing subcontractors to avoid MIL-SPEC parts, and suppliers to withdraw from defense business, leaving

more of the field to foreign suppliers; and (4) inadequate U.S. competitiveness in dual-use technologies, and lower levels of U.S. government and industry leadership and effort in such new technologies as flat panel displays and high resolution systems.

2. Systems

- Radar, display and missile systems are almost completely dependent on foreign sources for ceramic packaging, and high dependence on a few foreign sources for semiconductor silicon and gallium arsenide materials was found.

- Missile and engine systems were found to rely heavily on foreign machine tools and numerically controlled production equipment, ranging from 50 to 100 percent at important prime and component manufacturers.

- Display and radar systems in particular are dependent on a single source or small number of sources in Japan and West Germany for specialized ferrite, optical, and glass filter products.

- High and growing dependence on foreign sources was found for radar systems in photolithography equipment for semiconductor production.

- Dependence on foreign technologies in flat panel and high resolution systems is expected to grow because of a lack of U.S. production and integration capability, and strong R&D leadership in Japan and Europe.

3. Policies and Practices

- Trends in microelectronics parts used in radar are away from MIL-SPEC devices, fabricated and assembled domestically, toward MIL-STD-883-screened devices, which are predominantly assembled offshore. A primary factor keeping the bulk of defense microelectronics parts, packaging, and assembly, and to a lesser degree, wafer fabrication, onshore is DoD's requirement for MIL-SPEC parts. Sourcing of microelectronics parts is shifting away from MIL-SPEC devices, fabricated and assembled domestically, toward MIL-STD-883-screened devices that are predominantly assembled offshore.

- Concerns expressed most frequently by defense system contractors interviewed were those relating to the cost of capital, difficulties in obtaining defense R&D funding, tax rules, and accounting requirements which, they maintain, needlessly limit R&D and investment resources.

- DoD policies and practices said by contractors to increase costs of doing defense business and thereby to discourage domestic competition include: (1) military standards and specifications, (2) testing and screening procedures, (3) certification and qualification costs, (4) audit and quality assurance procedures, (5) cost accounting rules, (6) second-sourcing and data rights requirements, and (7) export controls.

- Lack of systems that track sourcing of parts and components makes it difficult and costly to determine the extent, let alone the significance, of defense system sourcing of foreign technologies. Both the extent of foreign sourcing and effort required to identify it expands as tracking moves down the supply chain.

ANNEX I
AIRCRAFT DISPLAYS

A. INTRODUCTION

Aircraft displays in particular were chosen for this study because of their broad application in both military and commercial aircraft. An aircraft cockpit requires a great deal of advanced technology in both design and manufacturing. The study concentrates on displays manufactured for the F/A-18 aircraft, the AV-8B aircraft, and the P-7 aircraft, but information on ATF/F-16 and F15 was also obtained.

Aircraft displays include a wide range of devices that provide aircraft crew members with information determined or transmitted by various sensors both in the air and on the ground. The study assessed two types of displays: cathode ray tube (CRT) and flat panel displays. With the emergence of flat panel technology, cockpit designers have a choice of flat panel as well as the traditional cathode ray tube displays. Sourcing data was obtained on both technologies.

The foreign sourcing issue is germane to both CRT and flat panel technologies but for different reasons. CRT assembly and component production are shifting to foreign locations which have gained an edge in production costs and manufacturing quality in this established but still evolving technology. By contrast, the Japanese lead in flat-panel technology is well documented in both study findings and in open literature.[1]

The study found foreign sourcing of significant materials and components in cockpit CRT displays. Most such sourcing is due to the decline of domestic production capabilities, with a few instances of special foreign technology advantages. For this reason, current foreign sourcing for CRTs could be replaced, at a cost, by development of domestic capabilities within periods ranging from roughly six months to over a year in all but certain optical filters, filter glass, glass bulbs, and ferrite coils. For the latter it could take up to five or six years and considerable expense to catch up with foreign technologies, retrain skilled personnel, and develop and qualify economically viable plants.

The limited scope of U.S. capability in flat panel technologies for defense systems appears more serious. Except for Litton-Canada, a U.S.-owned subsidiary,

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1 See "Computers: Japan Comes on Strong," *Business Week*, 23 October 1989, and "Flat Panel Displays Displace Large, Heavy, Power-Hungry CRTs," Lawrence E. Tannas, Jr., *IEEE Spectrum*, September, 1989, p. 34-35.

there is no U.S. LCD flat panel developer in North America with a clearly viable manufacturing capability, financial base, and proven system integration capability. Several U.S. firms and labs have developed flat panel technologies, but have failed to establish them on sustainable commercial footing. Several major European firms have begun to establish a manufacturing and R&D presence in the U.S., mainly through acquisition of American facilities. Whether they will become a significant factor in future as suppliers of flat panel technology for DoD systems remains to be seen.

B. METHODOLOGY

Permission to pursue the investigation was given by the Commanding Officer of the Naval Air Systems Command (NAVAIR). Invaluable assistance was given by program offices and personnel of the Avionics Division of NAVAIR as well as other U.S. Navy personnel and Army and Air Force personnel. Investigations were conducted at the following facilities: McDonnell Douglas in St. Louis, Missouri, Astronautics Corp. in Milwaukee, Wisconsin, Litton Canadian Toronto, Canada, Wright Patterson AFB in Dayton, Ohio, Naval Avionics Facility in Indianapolis, Indiana, Kaiser Electronics in San Jose, California, and Naval Air Systems Command in Washington, DC. In addition, other meetings were held with the President of the Society of Information Displays and the Chief of the Display Devices and Technology Branch, U.S. Army, Ft. Monmouth. Numerous telephone calls to industry and government personnel completed the process of data gathering.

In seeking data for determining current levels of foreign sourcing in display manufacturing, no adequate overall defense tracking system or database for determining national ownership of supplier firms, let alone their financing sources was found. Many U.S.-based vendors actually supply parts from foreign firms with which they have agreements. Thus, it is not enough to identify the plant location of the vendor to validate the country source of any part. As a result, these data gaps required part-by-part and company-by-company data searches to conduct the study.

C. FINDINGS

1. System Foreign Sourcing

a. F/A-18 Aircraft

The F/A-18 aircraft, developed by McDonnell Douglas and Northrop, has been in production since 1981. The F/A-18 has both a fighter and an attack mission operating from aircraft carriers. The F/A-18 aircraft displays consists of a head up

display (HUD), multipurpose display indicator (MDI), multipurpose display repeater indicator (MDRI), and multipurpose color display (MPCD).

The HUD was developed for McDonnell Douglas by Kaiser Electronics. The CRT within the HUD is provided by Thomas Electronics. The MDI has a CRT manufactured by Hughes and all parts of the CRT are manufactured in the U.S. There are three MDRIs in the back seat of the two seat F/A-18. The MDRI has a CRT obtained from dual sources: Thomas Electronics (U.S.) and Raytheon (U.S.). The MPCD was developed by Smiths Industries in Cheltenham, England.

Kaiser obtains the filter glass and the filter for the HUD from Hoya (Japan). The glass is bought by lot and *Kaiser personnel estimated that it would take five to six years to get a U.S. capability because most advanced filter technology is located in Japan.*[2] Castings for the HUD and MDI are manufactured in Canada because of an F-18 offset agreement between McDonnell Douglas and Canada. A summary of foreign sourced parts is presented in Table II.1. and Table II.2 for summary.

Kaiser and Litton manufacture the MDRI with the CRTs from Thomas Electronics and Raytheon. Nippon Ferrites supplies the ferrite cores. It does so for several reasons. First, it is willing to work with Syntronic in order to produce a custom-designed part. Second, it is willing to make the investment necessary to produce a component with a relatively limited lot size. Third, the complexity of the ferrite core rules out using any U.S. manufacturers as they are currently tooled. A summary of foreign sourcing can be found in Table II.3.

Table II.1
F/A-18 HEAD UP DISPLAY ASSEMBLY

Component	Vendor	Sub Component	Sub Vendor
Filter glass	Kaiser	N/A	Hoya (Japan)
Filter	Kaiser	N/A	Hoya (Japan)
CRT	Thomas Electronics	Glass Bulb	Glaswerk Wertheim (FRG)

2 Corning used to be a supplier many years ago but ceased production because of low volume. Schott from West Germany is an alternate source.

Table II.2 F/A-18 MULTIPURPOSE DISPLAY INDICATOR			
Component	Vendor	Sub Component	Sub Vendor
Filter glass	Kaiser	N/A	Hoya (JAPAN)
Filter	Kaiser	N/A	Hoya (JAPAN)

Table II.3 F/A-18 AND AV-8B MULTIPURPOSE DISPLAY REPEATED INDICATOR			
Component	Vendor	Sub Component	Sub Vendor
CRT	Thomas Electronics	Glass Bulb	Sibascon (Japan)
CRT York	Syntronic	Molded Ferrite	Nippon (Japan)

Syntronic, which provides about 60 percent of all coils (yokes) for CRTs in the free world, relies exclusively on Japanese sources for its ferrite cores. This was not always the case. For over 20 years, Stackpole Carbon in St. Mary's, PA. was the principle ferrite source for Syntronic. In April 1987, as a result of ongoing labor problems, Stackpole went out of business. The cost to Syntronic for retooling with Nippon Ferrites (Japan) was around $200,000—a large amount for a $6 million per year company. The company also had a second source from 1978 to 1984 in Indiana General which was eventually sold to TDK (Japan), which terminated its ferrite coil business. Other potential ferrite sources are Fujitsu (Japan), Thomson CSF (France), and two Korean companies owned by Thomson, but none have yet qualified. Syntronic continues to search for a second source.

Most of the components of the MPCD were developed by Smiths Industries (U.K.), which received R&D funds from the U.K. Ministry of Defense. A summary of foreign sourcing appears in Table II.4. The high voltage supply unit, cathode ray tube, and key panel were bought in the U.S. from U.S. suppliers. Tektronix reported that they obtain the critical optical filter from Wamco (U.S.) which in turn obtains the filter from the Wakoh Corporation (Japan). Wakoh has the rights to use a unique domestically produced (in Japan) proprietary material to manufacture the

filter. Thus this filter, which has a unique application in a color CRT, is obtained from Wakoh. The vendor for the CRT yoke assembly used in the MPCD is Syntronic. As noted above, Syntronic obtains these coils from Nippon Ferrites.

Table II.4
F/A-18 AND AV-8B MULTI-PURPOSE COLOR DISPLAY

Component	Vendor	Sub Component	Sub Vendor
CRT Optical Filter	Wamco	Optical Filter	Wakoh (Japan)
CRT Yoke	Syntronic	Molded Ferrite	Nippon (Japan)
CRT	Tektronix	Enhancement Filter	Shott (FRG)

Two shop-replaceable assemblies (electronic cards) were developed by the Smiths Industries, Clearwater, Florida facility which also provided some test equipment. Other support equipment was developed by McDonnell Douglas and other U.S. firms. The display is assembled in Cheltenham, England. However, Smiths personnel have indicated that the Clearwater facility could manufacture the entire MPCD, if required. Further analysis may prove this is questionable.

b. AV-8B Aircraft

The AV-8B aircraft, developed by McDonnell Douglas and British Aerospace (BAe), has been in full production since 1985. The primary mission of the AV-8B is to provide responsive close air support for ground forces. Cockpit displays consist of one Smiths (U.K.) HUD, two Kaiser Electronics (U.S.) MDRIs, and a Smiths (U.K.) MPCD. No data was obtained on the Smiths HUD, although it is known that Smiths and the British Ministry of Defense have had a long association on the development of the system since the early 1970s. The technology for the HUD was developed in the U.K. The Kaiser and Litton MDRI's both have CRTs built by Thomas Electronics (U.S.) and Raytheon (U.S.). Details of foreign sourced components used by Thomas Electronics and Raytheon CRTs are provided in Tables II.4 and II.5.

c. P-7 Aircraft

The P-7 aircraft is currently being developed by Lockheed Aeronautical Systems Company. Initial Operational Capability is scheduled for 1993. The P-7 has

six high-intensity, high-performance, color-beam-index, cathode ray tube display units (DUs). The system integrator for the P-7 electronic display system (EDS) is Astronautics Corporation of America. Astronautics, in turn, has awarded a contract for the CRTs to Thomas Electronics, Wayne, NJ.[3]

Table II.5
P-7 MULTI-PURPOSE COLOR DISPLAYS

Component	Vendor	Sub Component	Sub Vendor
CRT of DU	Thomas Electronics	Phosphor-Red	Nichia Chemical (Japan)
CRT of DU	Thomas Electronics	Phosphor-Green	Nichia Chemical
CRT of DU	Thomas Electronics	Phosphor-Blue	Nichia Chemical
CRT of DU	Thomas Electronics	Phosphor-Index	Nichia Chemical
CRT of DU	Thomas Electronics	Glass Funnel	Glaswerk Wertheim (FRG)
CRT of DU	Thomas Electronics	Glass Faceplate	Glaswerk Wertheim
CRT of DU	Smith	CRT	Mitsutbishi

The CRT for the P-7 uses color-beam indexing which requires only one gun compared to three in conventional CRTs. Different phosphors are used to obtain the required color, but writing to the display is similar to that in a monochrome display. Beam current is reduced so that the display may not need forced air cooling, and the display is NVG compatible.

This study concentrated on the display itself rather than supporting electronics. The CRT is the most critical and costly of the display components. The CRT is made up of components such as the glass bulb, deflection coils, phosphors, and cathode (see Figure II.1).

As indicated earlier, Thomas Electronics is purchasing some CRT components, such as phosphors, funnels, and faceplates, from foreign sources other than Canada. The phosphors are purchased from Nichia (Japan) and are superior to

3 Ferranti of the UK was originally teamed with Astronautics as the DU supplier, but Ferranti would not accept the terms and conditions of the Lockheed contract requirements after Astronautics won the award. Sony also failed to come to terms with Astronautics, citing the government of Japan's policy of not exporting military equipment as the reason. Satisfactory financial arrangements could not be determined with Tektronix.

domestic sources because of luminous efficiency, uniformity, and usability. Should Nichia phosphors be unavailable, Thomas Electronics could purchase from a domestic or British source. However, desired quality standards may not be immediately met, but could be met in time.

Other critical items are the glass funnels and faceplates manufactured by Glaswerk Wertheim, Wertheim, Germany; Nippon Electric Glass, Osaka, Japan; and Sibascon, Tokyo, Japan. Data on these parts are summarized in Table II.5. These companies have the molds which are necessary to fabricate these glass components. In case of a national emergency, these glass components could be tooled by Lancaster Glass Corporation of Lancaster, Ohio, provided appropriately skilled workers and tools are available.[4]

The determination of system parts for the P-7 cockpit display is not mature enough for further analysis at this time. However, the data obtained is sufficient to indicate that the displays will use some critical foreign sourcing. The mission (back) end of the P-7 aircraft contains most of the avionics that are also used in the P-3C Update IV. This includes five 19" color displays (CDs) furnished by Smith's Industries (U.K.) using Mitsubishi (Japan) CRTs and five flat panel 18" x 5.5" AC plasma displays (programmable electro plasma entry panel).

d. Aircraft Programs Using Flat Panel Technology

Flat panel technology is slowly replacing the conventional CRTs. Flat panel displays have become more numerous as digital avionics replace analog instrumentation.

The ATF and F-16 use a flat panel liquid crystal display (LCD) designed by General Electric. Subsequently, the technology and manufacturing rights, sold by General Electric, have moved through Thomson CSF (France) to Sextant (France).

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4 At one time Corning and later Lancaster Glass were the dominant suppliers of special-purpose bulbs for CRTs. However, due to lack of demand for electrostatic CRTs, Lancaster closed down one production line which was exclusively producing hand-blown bulbs for electrostatic CRTs. Thus, after failing to convince DESC to make a one-time buy of the CRTs, Lancaster has focused exclusively on machine-pressed bulbs for electromagnetic CRTs. Lancaster and NEG together account for almost all of the bulb purchases by Thomas Electronics. Lancaster has faced increasing competition from foreign firms, particularly NEG. Although Lancaster claims that NEG has sold the bulbs at prices which represent about 60 percent of manufacturing costs, it did not file dumping claims. Corning made a corporate decision to get out of the business due to the low volume requirements. Making these CRTs was no longer an economical process. Additionally, Thomas Electronics purchases molds from Glaswerk Wertheim, NEG, and Sibascon. It would require 18-24 weeks for a U.S. supplier to meet Thomas Electronic's current demands in this area.

Negotiations are underway for Sextant to supply the panels to Kaiser, the U.S. integrator for this aircraft.

The F-15 display, built by Honeywell, includes a 5" x 5" color CRT using a Matsushita cathode ray tube. The USAF has provided $2 million to Tektronix to build a U.S. version that also has some technical improvements. Foreign sourcing of the filter and coil is the same as noted for the F/A-18 MPCD.

2. Production Manufacturing Equipment

Several display manufacturers have noted that many of the production machines at their vendor's plants come from Japan and Germany. In addition, during visits to several system manufacturers, foreign-made production equipment was noted. The factory test equipment, intermediate, and operational test equipment for the F/A-18 and AV-8B MPCD were all built with commercially available U.S. parts, some of which contain foreign electronics (for example, Hewlett Packard computers).

3. U.S. Industry Position

The competitive posture of the U.S. display industry is worrisome. The chairman of the Society for Information Displays, Mr. Tannas, has stated that the U.S. position in displays is weakening on a daily basis. On the other hand, Japan is growing stronger and appears bound to gain gradual control of the market. A number of indicators support this claim. Because of its vertical integration, Japanese industry seems better able to pursue long term strategies, including investing in new technologies and developing new products. Japanese industry inserts innovative technology in consumer products to test and develop new markets. For example, Japan is now developing fifteen-foot-square displays for billboards and theaters, an innovative use for displays.

Giant Technology Corporation, made up of Asahi Glass Co., Casio Computer Co., Hitachi Ltd., NEC Corporation, Sanyo Electric Co., Seiko-Epson Co., and Sharp Corporation was set up to explore new display products.[5] The Corporation is developing polycrystalline silicon driver circuits with horizontal operating rates of 100 KHz and vertical rates of 10 MHz.

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5 For more information on Giant Technology Corporation, see "Defense Department, Japan in Negotiations for Flat-Panel Displays," *New Technology Week*, 20 November, 1989. Also see "Japanese Developments in High Definition Television," by Tech Search International, Austin, Texas, September, 1989.

The best production stepper lithography machines are made in Japan by Cannon and Nikon. This technology is one of the base technologies for flat panel manufacturing. Japan also seems to be becoming dominant in the thin film transistor (TFT) liquid crystal display (LCD) technology and manufacturing.

According to the Society of Information Displays, the Japanese have dominated publication of relevant technical papers over the past five years. Several U.S. display experts have recently expressed the opinion that Japan is conducting the best display research.

U.S. defense policy has traditionally counted on our technology advantage to offset numerical superiority of adversaries. An integral function of any defense system is to convey information effectively to its operator. As the technological demands on systems increase, so does the burden of informing the operator about the status of the system—position, readiness, etc. In order for the U.S. to maintain its technological advantage, displays must be able to relay growing amounts of important information in a wide array of defense systems. Displays were selected for study in part because of their breadth of defense applications.

ANNEX II
AIRCRAFT RADAR

A. INTRODUCTION

Three versions of the F-16 Radar—the AN/APG-66, the AN/APG-68, and the AN/APG-68 with advanced programmable signal processor (APSP)—were selected for investigation because they represent state-of-the-art radar systems and have the potential of illustrating foreign sourcing trends. The objective of this system study is to identify and analyze the sourcing of microelectronic devices used in the Air Force F-16 radars. The F-16 radars were designed and produced by Westinghouse.

B. METHODOLOGY

The initial step in this study was to identify the semiconductor devices in the radars studied. Interviews with selected manufacturers of microelectronic devices were conducted to assess the level and extent of reliance on foreign sources of materials, equipment, labor, and/or facilities. Almost 100 manufacturers were identified, accounting for approximately three-quarters of the microelectronics device configurations. The data presented covers 334 microelectronic device configurations found in use in the F-16 Radars (approximately 35 percent of the total).

Visits were made to four of the principal manufacturers of radar microelectronic parts: Texas Instruments, National Semiconductor, Motorola, and Solitron Devices. A telephone interview was also conducted with LSI Logic concerning configurable gate arrays (CGA) used in the APSP since these devices represent the leading edge application-specific integrated circuit technology used in the F-16 radar.

C. BACKGROUND ON CERTIFICATION REQUIREMENTS

Much confusion surrounds the various types of commercial and military-qualified microelectronics devices. These differences include purchasing practices, quality certification and testing requirements. Adding to the confusion is that defense systems may also permit procurement of commercial microelectronic devices under certain conditions. Table II.6 and the following discussion attempt to illustrate some of the distinctions.

Table II.6
DEVICE CATEGORIES

Device Category	Audited/ Certified By	Die Fabrication	Assembly & Test	Process & Test Requirements
Semiconductor Discretes				
MIL-S-19500 (JAN, JAN-TX, JAN TXV, JAN S)	DoD	Onshore	Offshore permitted if possesses onshore certified line (except JAN S and JANTXV)	MIL-STD-750
Source Control Drawings (SCD)	Manufacturer	Offshore permitted	Offshore permitted	MIL-STD-750
Off-the-Shelf Commercial	?	Offshore permitted	Offshore permitted	At some level below MIL-STD-750
Microcircuits (Including Hybrids)				
MIL-M-38510 (JAN B and JAN S)	DoD	Onshore	Onshore	MIL-STD-883
DESC/Standard Military Drawing (SMD)	Manufacturer	Offshore permitted	Offshore permitted	MIL-STD-883
883-Microcircuits (Vendor Part Numbers)	Manufacturer	Offshore permitted	Offshore permitted	MIL-STD-883
Source Control Drawings (SCD)	Manufacturer	Offshore permitted	Offshore permitted	MIL-STD-883
883 "Look-a-Like" (Commercial)	?	Offshore permitted	Offshore permitted	At some level below MIL-STD-883

All microcircuit devices, with the exception of commercial parts must comply with the requirements of MIL-STD-883, *Test Methods and Procedures for Microelectronics.* The highest levels of product quality assurance for microelectronic devices are referred to as MIL-SPEC JAN (Joint Army Navy) parts. They are specified in MIL-S-19500 and MIL-M-38510 for discrete and microcircuit devices

respectively. The JAN qualification process can take one to two years to complete, and the cost of full certification may range from $40,000 to $500,000 depending on the complexity of the processes involved. This qualification process addresses only a single specific device type; each new device must go through the process in order to be JAN certified.

Offshore assembly and test is permitted for *most* JAN device types, however, JAN S and JANTXV type devices must be assembled and tested onshore. JAN devices which are qualified to MIL-M-38510 must be both fabricated and assembled onshore, or at certified offshore facilities.

Source controlled drawings (SCD) are generated by Original Equipment Manufacturers and must conform to their requirements.

The parts selection trends for the evolving F-16 Radars have been moving away from the MIL-SPEC (MIL-M-38510 and MIL-S-19500) type devices to MIL-STD-883 screened (SCD) devices that predominantly rely on offshore sources for assembly, and to a lesser extent for offshore wafer fabrication.

D. FINDINGS

1. Foreign Sourcing

Biases in the defense procurement system may encourage purchase from either onshore or offshore sources. For example, Westinghouse stated that it favored onshore sourcing during the design and development of the F-16 Radar. Westinghouse personnel indicated that, during initial competition for the contract to develop a radar for the F-16 aircraft, Westinghouse perceived that use of foreign sources would be a negative factor in criteria for selection of the contractor. Westinghouse personnel recalled that portions of the original design concept relied on offshore microelectronic devices, but as a consequence of the prevailing negative perception of foreign sources, the concept was changed to reduce the use of foreign sourced microelectronic devices. By contrast, procurements under co-production or offset arrangements, and cost-saving pressures often favor offshore sources.

a. Wafer Fabrication

(1) Facilities

All of the individual microelectronic circuits (or die) used in the semiconductor integrated circuits (ICs) and discrete devices evaluated in this study were fabri-

cated at U.S. onshore companies. Texas Instruments indicated that all of the die for the F-16 radars came from U.S. plants (although it has seven offshore fabrication facilities). National Semiconductor reported that between 75 and 80 percent of its wafer fabrication for both commercial and military purposes is onshore. Motorola stated that all of its JAN wafers are fabricated onshore; however, it fabricates and assembles the majority of its 883-screened products in Malaysia.

The die for the 14 power-application-type hybrid devices that were evaluated in this study were either fabricated onshore or acquired from U.S. onshore distributors. Forty-five different die types were identified as being used in the 14 hybrids studied. Of these die, 14 were fabricated onshore by Solitron and the other 31 were acquired from U.S. distributors. Approximately half of the die acquired from distributors were fabricated at U.S. onshore facilities. The distributors indicated that the remaining die could have come from either onshore or offshore sources.

(2) Materials

Most of the U.S. wafer fabrication facilities rely on foreign-owned sources of silicon; however, most other materials needed in the fabrication process were generally available onshore. Both National Semiconductor and Motorola indicated that they obtain silicon offshore or from onshore sources owned by foreign companies. However, Texas Instruments manufactures its own silicon at its plant in Texas. This facility has been growing its own silicon for at least 25 years. Other silicon supply sources identified during this study were:

- SEH, a Japanese-owned company, has five plants in Japan, one in Malaysia, and one in Washington State.
- MEMC, a German owned company with headquarters in Missouri, has plants in South Carolina, Malaysia, and Italy.
- Wacker, a German company, has a plant in Oregon.
- SILTEC, owned by Mitsubishi (Japan), has a manufacturing facility in Oregon.
- OTC (Osaka Titanium), a Japanese company, recently purchased two U.S. locations that provide silicon wafers: Cincinnatti Milicron and US Semi.
- Reticon, a U.S. company located in Pennsylvania, was identified as a source for wafers used in the fabrication of discretes.

- NBK, recently purchased by Kawasaki (Japan), has manufacturing facilities in California.

(3) Manufacturing Equipment

The IC manufacturers surveyed indicated a high degree of dependence on Japanese lithography equipment, although a few U.S. companies were mentioned as potential alternative sources for lithography and stepper equipment. Canon and Nikon, both Japanese companies, were the most frequently mentioned sources of lithography equipment. Other stepper companies mentioned include: GCA (General Signal), a U.S.-based company; Ultratech (also General Signal), a U.S.-owned company; and ASM, a Dutch-owned company.

One of the IC manufacturers indicated that there were very few incentives to acquire steppers from relatively small producers like GCA (with an estimated capacity of approximately 60 units per year) when they could deal with Nikon (with an estimated capacity of approximately 500 units per year). The principal reason was the greater confidence of the manufacturer in the large producers' future. Interestingly, the current *yearly* capacity of Nikon approximates the *total* installed operating units produced by either Ultratech or GCA today.

IC manufacturers visited indicated that they have more confidence in the equipment produced offshore because of the manufacturers' better reliability, quality, and service and their general concern over the future of U.S. companies. At the same time, there exists a general belief among those visited during this study, that U.S. component manufacturers do not receive "first-line" Japanese manufacturing equipment. They perceive that the Japanese equipment manufacturers provide "state-of-the-art" equipment to Japanese firms first, thereby, keeping U.S. companies one generation behind.

All other wafer fabrication equipment appears to be available from onshore sources. However, the Japanese have been very aggressive in many other equipment areas, including electron beam (E-beam) and focused ion beam equipment for lithographic photomask making and direct-write on the wafer substrate, integrated circuit test equipment, ion implanters, and deposition equipment. U.S. firms in these areas generally are relatively small and under-capitalized.

b. Packaging and Assembly

(1) Facilities

The study found a significant portion of the F-16 radar parts types were assembled offshore. Table II.7 compares the percentages of onshore and offshore assembled parts. The table shows that 28.3 percent of the F-16 radar device configurations evaluated were packaged and assembled offshore. However, the offshore percentages increase to 45.3 percent and 67.9 percent for MIL-S-19500 and SCD part types respectively, when the MIL-M-38510 parts types (MIL-SPEC parts which are restricted to onshore assembly) are removed.

Table II.7
F-16 RADAR PARTS TYPES ASSEMBLED ON AND OFFSHORE

	Percentage Assembled	
	Onshore	Offshore
SCD	32.1	67.9
MIL-M-38510	100.0	0.0
MIL-S-19500	54.7	45.3
Totals	71.7	28.3

The 14 hybrid devices evaluated were all power application devices. These devices are very specialized power hybrids for military and aerospace applications. The hybrid manufacturer visited, Solitron Devices, produces its own packages, and assembles the hybrids in its Florida facility. Westinghouse personnel observed that there exist very few power related hybrid producers that meet the military specifications, and that this technology is critical to DoD weapon systems. Solitron personnel indicated that at the present time, their products essentially constitute a niche-market and they do not face significant competition with offshore sources.

Texas Instruments personnel indicated that virtually all of its JAN B and JAN S parts are assembled in Texas. National Semiconductor noted that between 70 and 80 percent of the assembly and testing of its military components is offshore. Approximately 98 percent of National's commercial assembly and testing is done in offshore facilities. The bulk of this assembly and testing is done in National's

Singapore facilities, where only 10 percent of the output is for military applications. Motorola indicated that almost all of its JAN devices are assembled onshore. However, many of the 883-screened devices are assembled in Malaysia.

(2) Materials

The microelectronic devices evaluated in this study were found to be heavily dependent on foreign sources for packaging material. The primary items dependent on foreign sources were: (1) ceramic packages, lids and covers, and lead-frames used on semiconductor and IC devices; and (2) ceramic feed-throughs used on power hybrid devices (see Figure II.1). Economic factors coupled with source availability favored offshore suppliers.

With few exceptions, the ceramics were acquired from offshore sources or from sources in the U.S. that are foreign owned. The primary source for ceramics is Kyocera, a Japanese manufacturer. Kyocera has plants both in Japan and California. The study team received conflicting views during the visits relative to the responsiveness of Kyocera. One source indicated that Kyocera is very responsive to its needs, while another indicated that Kyocera had (on several occasions) unilaterally altered critical specification properties that ultimately effected device quality.

Other ceramic package manufacturers included NTK, Naruni, and MPI. NTK and Naruni are Japanese companies located in Japan. MPI is a U.S.-owned company with all of its manufacturing performed in Singapore.

Ceramic packages are critical to commercial applications as well as to DoD applications. One microelectronics manufacturer estimated that only about 20 percent of worldwide ceramic packages are used in military applications. As with most of the microelectronics technology areas, the commercial market place is the driving force behind requirements.

Most covers (caps and lids) were acquired from the same manufacturers that provided the ceramic packages. The primary differences indicated by the percentage changes in the table are due to the U.S. sources for metal cans and for side-brazed lids.

Lead Frame

		APG-66	APG-68	APG-68 (new)
883 on shore	(%)	86	80	68
883 off shore	(%)	14	20	32
38510 on shore	(%)	99	81	70
38510 off shore	(%)	1	19	30

Ceramic Base

		APG-66	APG-68	APG-68 (new)
883 on shore	(%)	0	0	0
883 off shore	(%)	100	100	100
38510 on shore	(%)	2	1	1
38510 off shore	(%)	98	99	99

Cover

		APG-66	APG-68	APG-68 (new)
883 on shore	(%)	5	8	9
883 off shore	(%)	95	92	91
38510 on shore	(%)	5	17	26
38510 off shore	(%)	95	83	74

Figure II.1
SOURCES OF PACKAGING/ASSEMBLY MATERIALS[6]

6 Parts in the new configuration AP-68 and not used in the APG-66.

(3) Assembly Equipment

Assembly equipment for microelectronic devices includes the saws used for wafer-cutting, furnaces, and various bonders, welders, and soldering equipment. All the microelectronics manufacturers surveyed indicated that U.S. sources could be found for assembly equipment. The sources for assembly equipment used in the various facilities varied significantly. Specific equipment choices were justified on economic as well as availability factors.

The four companies surveyed found the use of foreign equipment varied markedly, depending, in part, on whether the equipment is used for MIL-M-38510 or 883-screened components. In general, the assembly which takes place offshore uses foreign equipment. This equipment tends to represent the "state-of-the-art" available to US manufacturers, and its use offshore is driven by the high volume of both commercial and 883-screened products assembled there.

The extent of foreign equipment used in the assembly of MIL-M-38510 parts and the relatively small fraction of 883-screened parts assembled onshore varies by company. Texas Instruments produces almost all its own assembly equipment for its JAN parts. National has a mix of US and foreign sources for its assembly equipment. Motorola indicated that it relies extensively on foreign equipment in its assembly process. U.S. manufacturers surveyed who rely on foreign suppliers indicated that they may not receive the "state-of-the-art" equipment from foreign suppliers.

c. DoD Costs and Quality Requirements

(1) Costs

Table II.8 compares the typical cost differences for a hermetically packaged large scale integrated (LSI) circuit for three categories: commercial, MIL-STD-883 Class B Screened, and full MIL-M-38510 level (on QPL).

2. Quality Requirements

DoD is currently developing a new quality assurance concept that will focus on the microelectronic device manufacturer's process controls in support of a qualified manufacturers list (QML). The QML concept will qualify a company's lines and processes, and thereby, the devices produced on those lines, whereas the QPL concept involves device by device qualification.

Table II.8 SEMICONDUCTOR PRICING FACTORS (ASSEMBLY COSTS IN DOLLARS)			
Category	Commercial	Screened	QPL
Die Cost	2.00	2.00	2.96
Package Cost	5.00	5.00	5.00
Assembly Cost	0.44	2.22	2.22
Pre-Cap Visual *(Yield, %)*	0.00 *(84%)*	0.15 *(71%)*	0.31 *(63%)*
Assembled Cost	8.86	13.27	16.64
Screening	0.00	0.72	0.82
Pre Burn-In Test *(Yield, %)*	0.00 *(100%)*	0.23 *(74%)*	0.46 *(70%)*
Burn-In Cost	0.00	0.64	1.10
Final Test Cost *(Yield, %)*	0.23 *(8%)*	0.68 *(88%)*	2.28 *(87%)*
Qualification	0.00	0.00	5.70
Total Factory Cost	10.84	23.32	39.93

Source: Semiconductor Economics Report, Vol. 3, No. 9.

IC manufacturers were all very supportive of this new concept because it would reduce the cost of their products and streamline the certification process without adversely impacting product quality. Another benefit of the QML concept is the potential to reduce the burden of source inspections. DoD regulations require that Government contractors audit each supplier (as many as 80 audits per year for large microelectronics manufacturers), and the cost of the audits must be passed on to the customers.

The Semiconductor Industry Association (SIA) recently took the following position on the QML concept: The QML system should be applied to all of the industry's factories, both onshore and offshore, and to all technologies, new and old. However, it must be recognized that once the QML system has progressed to offshore facilities and subcontractors can purchase QML products made in foreign countries, the volumes of like product produced in onshore facilities will drop, U.S. assembly and test factories will close and the U.S. industry base to support our national defense will disappear. Under the current system it is the QPL and the order of precedence that is keeping some production onshore.

To understand why QML will drive product offshore, one should recognize that offshore production is now 95 percent commercial, and military overhead costs are shared with the commercial volume and market demand. Military product run in the same factories enjoy a much lower overhead cost burden than does product produced on U.S. lines. Onshore product will always bear a cost "premium" for this reason, unless consistent and increasing volume can be maintained. Onshore product prices then, being higher than offshore, will force procurement of QML product produced offshore and will reduce onshore volume, forcing manufacturers to close factories, or at best to raise prices on any remaining low volume left on U.S. lines, like space (Class "S"). As volume diminishes, manufacturers may well drop entire lines and use available onshore square footage for alternate expansion.[7]

The manufacturers visited agreed with the SIA position. They went on to conclude that if DoD decides to put both QML and JAN parts at the same level in the order of precedence for parts selection, the onshore JAN facilities will close down. Although they favor the QML concept, they also believe that the new QML concept will exacerbate current foreign dependence problems if foreign sources are permitted to participate.

7 SIA/GPC, Position Paper, G. Cohrt, Chairman, Summer 1989.

ANNEX III
AIR TO AIR MISSILES

A. INTRODUCTION

Sparrow and AMRAAM vehicles were chosen for this study because of their importance to the U.S. air superiority mission, and because of system designs that represent different points in time. Sparrow, although designed in the mid 1950s, embodies mainly 1970s technology, and AMRAAM represents largely 1980s technology. The AIM-7 "Sparrow" and the AIM-120A Advanced Medium Range Air-to-Air Missile (AMRAAM) missiles perform roughly similar missions: radar-guided, medium-range air intercept of hostile aircraft. AMRAAM has been designed as a follow-on to Sparrow, and as a result bears some resemblance to its predecessor.

AMRAAM is currently in low rate production, with the 400 missiles of Lot 1 due for delivery by the end of 1989. However, it is doubtful that the two vendors will be finished by that date. Production of the full acquisition of 22,000 missiles for the Air Force and 7,000 for the Navy is slated to continue into the next century. Thus, the need to procure the components for this system represents an important demand for the U.S. industrial base through the 1990s.

B. METHODOLOGY

Data for this section were obtained in several ways. First, background data were obtained from standard references such as *Jane's All the World's Aircraft, 1988-89* and *DMS Market Intelligence Service*. With the help of the Joint Service Program Officer for AMRAAM, Brigadier General Charles E. Franklin, at Eglin Air Force Base, Florida and Captain Jesse Stewart, Program Manager, Air-to-Air Missiles, Naval Air Systems Command, the prime contractors for AMRAAM (Hughes and Raytheon) and for Sparrow (Raytheon and General Dynamics) were contacted. These companies proved extremely helpful in providing parts lists and names of important suppliers (selected by total dollar value and by estimated amounts of lead time to qualify an alternate source). Then the main suppliers of subsystems and parts for both missile systems were contacted. Figure II.2 provides a flow chart of the primary contractors and subcontractors in the two missile programs. These include:

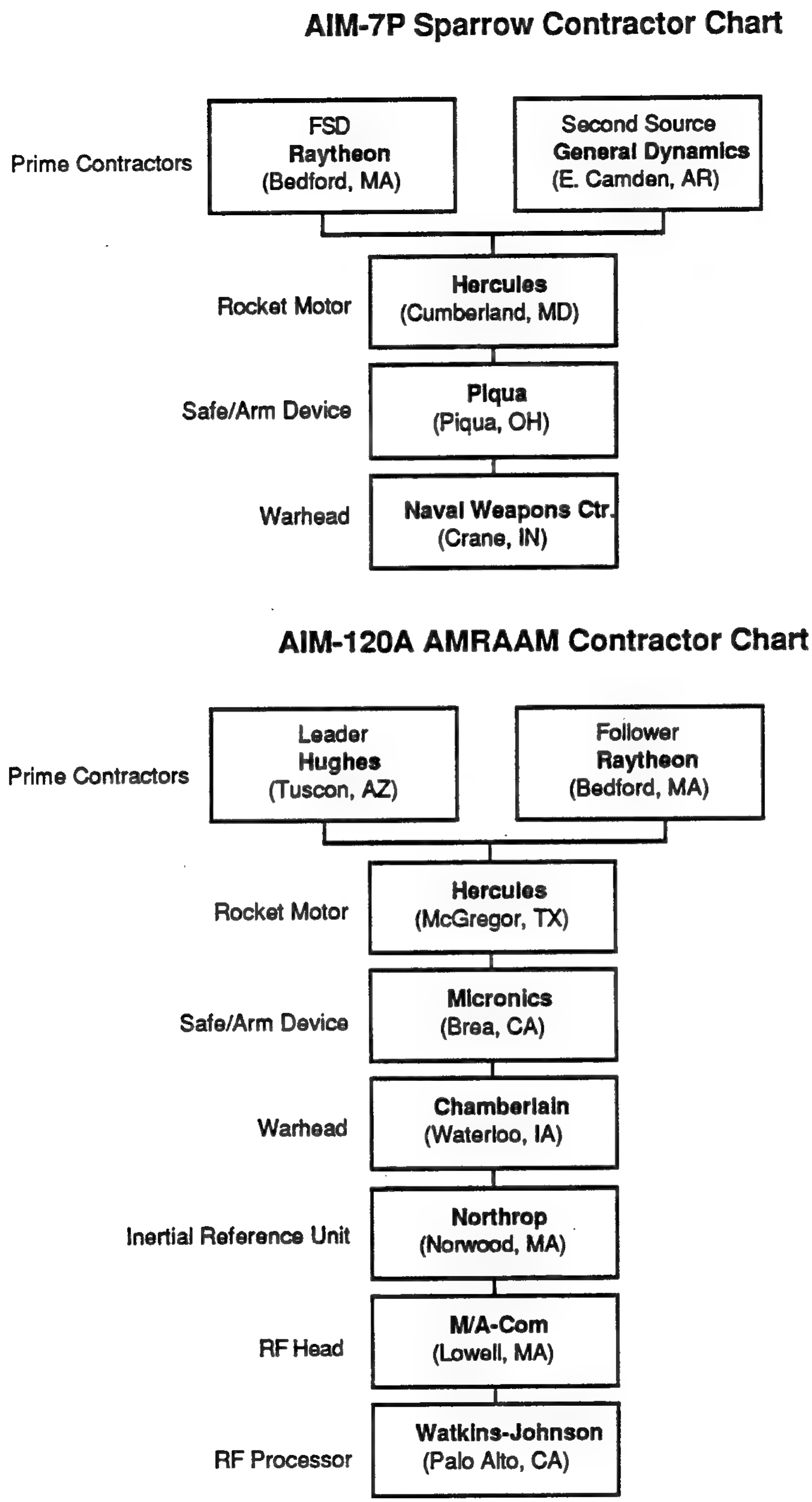


Figure II.2
MAIN CONTRACTORS TO AIM-7 AND AIM-120A

- Watkins-Johnson (AMRAAM) Palo Alto, CA;
- Piqua Engineering Co. (Sparrow, and if qualified, AMRAAM) Piqua, OH;
- Chamberlain Manufacturing (AMRAAM) Waterloo, IA;
- Eagle Picher Manufacturing (AMRAAM and Sparrow) Joplin, MO;
- Hercules (AMRAAM and Sparrow) McGregor, TX;
- Northrop (AMRAAM and Sparrow) Dedham, MA;
- M/A COM (AMRAAM and Sparrow) Lowell, MA;
- Corning Glass (AMRAAM and Sparrow) Corning, NY; and
- General Dynamics (Sparrow) E. Camden, AR (teleconference).

The manufacturers, with few exceptions, provided us with complete parts/suppliers lists. The data collected represent the major system contractors of the components in the AMRAAM and Sparrow. Manufacturing sites were also observed. System manufacturers identified approximately one thousand third-tier firms that supply parts and components for the subsystems that comprise the missiles. Time did not permit visits to third-tier vendors, but parts lists were obtained from some of these suppliers. In addition, it was determined whether companies which supply parts for the systems are owned by foreign parent companies. This proved to be complex and time-consuming.

C. FINDINGS

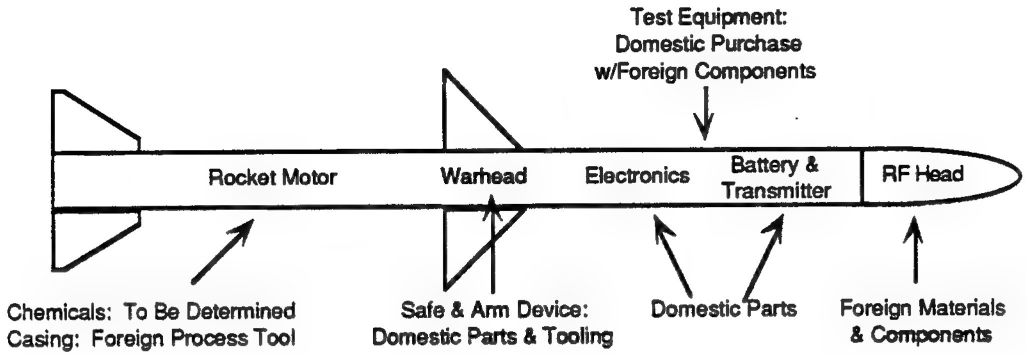
1. System Foreign Sourcing

Figure II.3 provides a graphic illustration of the components and processing tools from foreign sources. Findings are presented by major technology area; electronics, mechanical/structural, and chemical. Significant foreign-sourced items include:

AMRAAM actuator motors	Lucas Aerospace, United Kingdom
AMRAAM FETs and capacitors	Fujitsu, Japan
Rocket Propellant Chemical	Huls, Federal Republic of Germany
Raw materials (e.g., titanium, chromium)	Australia; South Africa
Numerically controlled machine tools	Japan; Federal Republic of Germany

For AMRAAM, not less than five of the suppliers to Raytheon are foreign-owned but U.S.-based manufacturers. One supplier each to Raytheon and M/A Com is located abroad. For Sparrow, only one of the firms supplying Raytheon is foreign owned. The number of foreign-owned firms is likely to be larger since the study checked only a sampling of the supplier universe.

Sparrow Subsystem Source Summary



AMRAAM Subsystem Source Summary

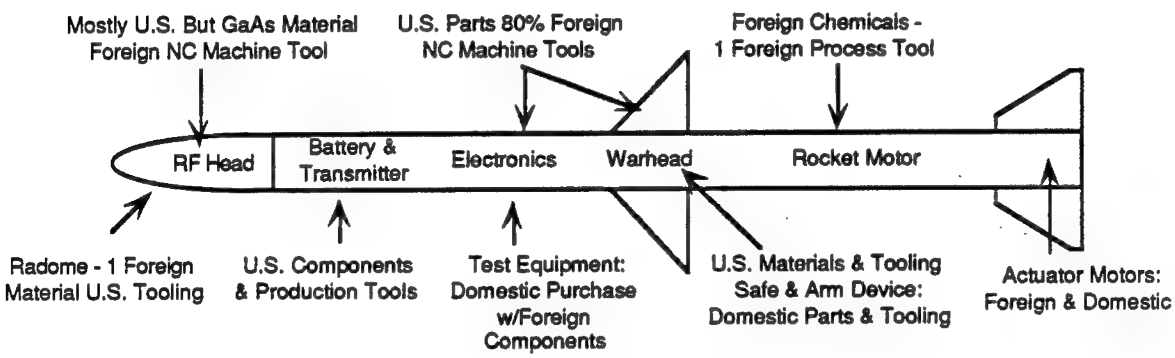


Figure II.3
SUMMARY OF OFFSHORE SOURCED ITEMS IN THE AIM-7 AND AIM-120A

a. Electronics

The electronics in the guidance and control section of the missile are critical to the advanced capabilities of the newest generations of air-to-air weaponry. In the AMRAAM, the electronics allow the pilot to launch the missile and leave the area. The guidance function is the major cost component of missiles. Seventy-seven percent of the AMRAAM unit cost is for the guidance section, with 34 percent of that being the Electronics Unit alone.[8]

8 AMRAAM APREP Decision Coordination Paper, p. E2-16.

The Sparrow's electronics suite is substantially less complex than AMRAAM, yet it exhibits the same high degree of cost concentration in the electronics components. Of the 25 components Raytheon identified as primary cost drivers, which account for 50 percent of the total purchased parts cost, 17 are electronic components.

Corporate management of the prime contractors advised us that with the exception of the Lucas actuator motor, they know of no foreign content directly contracted into either missile. However, a representative of the AMRAAM JSPO found during a tour of one factory that there were numerous microelectronic components labeled with offshore manufacturing locations. In fact, his informal survey of one circuit card revealed that the board contained 46 devices from five nations other than the U.S. His belief was that these devices were commercial components tested to the Mil-Std level. The Quality Assurance personnel at the JSPO investigated this situation and discovered that for the devices questioned, the Defense Electronics Supply Center (DESC) allows foreign manufacture if the firm complies with the appropriate testing and qualification standards. Additionally, the manufacturer must grant on-site inspection rights.

Foreign-produced commercial electronic components are generally selected because of limited domestic supply and substantial cost savings. Time constraints have precluded investigating the complete lower tier supplier base, but of the ten lower-tier electronic component companies contacted, all use some type of foreign produced production equipment or commercially produced components which could be manufactured offshore. Commodity devices such as integrated circuits purchased from National Semiconductor or Harris generally have some foreign content, either material or labor.

Another finding regarding microelectronics involves the manufacture of hybrid circuits. To produce these circuits, a manufacturer will often assemble specialized devices of its own manufacture with standard components purchased from distributors. Watkins-Johnson makes hybrids for AMRAAM and stated that it purchases unpackaged die from the least expensive source to be incorporated into their devices, without regard to country of origin. Its perception is that the proprietary components of its manufacture are the high value-added devices and the purchased circuits are commodities, which could be reverse engineered, if necessary. The assembled device is then tested to the Mil-Std level as though it were completely manufactured domestically. Since hybrid suppliers often bid these items under fixed price contracts, their most important criteria is cost. To many firms,

including Watkins-Johnson, cost is far more important than subcontractor vendor nationality, since it purchases thousands of microcircuits in a given year. Technology implications are important: if U.S. manufacturers are not in the business of developing these devices, they will lose the skills and personnel required to reenter production.

The raw materials required for microelectronics fabrication provide some offshore sourcing difficulties for the manufacturers. There are no competitively-priced domestic sources of high quality merchant gallium arsenide because demand in the U.S. is low relative to Japan. As a result, sources of the raw material are predominantly Japanese firms such as Fujitsu. The gallium arsenide is delivered to Watkins-Johnson in the form of a boule, or ingot. Watkins-Johnson slices the boule into wafers and completes the processing of the dice into completed circuits. If Watkins-Johnson were to lose its materials source, it would take at least one year to qualify a new source.

Many of the microcircuits for both missiles are packaged in ceramic chip carriers. These components are supplied by Kyocera, either from its plant in Japan or from its U.S. subsidiary in San Diego. We have been told by the JSPO that the quality of the U.S.-produced Kyocera products is not as high as the imported product, but the study obtained no contractor substantiation of this claim. Kyocera-U.S. is said to import the raw materials for its packages from Japan.

Block upgrades, such the AMRAAM Producibility Enhancement Program (APREP), have mixed effects on technology sourcing. On one hand, large-scale-integration (LSI) microcircuits being incorporated into the APREP modifications eliminate the need for numerous hybrid and other devices with offshore sources, such as discrete semiconductors. Use of LSI devices also reduces the parts counts for the electronics section as a whole. One APREP project, the upgrading of the digital subsystem, will modify three existing subsystems, the input/output function, the data processor, and the filter processor. The project will incorporate VLSI gate arrays and will reduce the LSI gate arrays from 29 to 19. For the whole subsystem, it will reduce parts count from 851 to 256, presumably including some currently sourced offshore. For M/A-Com, supplier of the radio-frequency head, the APREP program also has a sourcing disadvantage, however. The new MMICs replacing older parts will require gallium arsenide substrates which must be imported from West Germany. In this case, elimination of one type of offshore dependence has created another.

Almost all of the tests on the missile are performed by the primes and various subcontractors on automated test equipment (ATE). Without the capability of testing the guidance and control section, there would be no way to determine the func-

tionality of the system. In 1986, Raytheon performed an extensive surge and mobilization study. This study found that "the most imposing impediment to rapidly increasing Sparrow missile production is the lack of factory special test equipment."[9] Generally this equipment consists of commercial test components and computers configured to the needs of the specific test. This category of equipment poses a significant foreign sourcing issue. Hewlett-Packard, one of the largest U.S. firms in the test equipment market, completed a portion of the study detailing the surge/mobilization effects for its products. HP found that many semiconductors used in making its test equipment are foreign source dependent. Some of these were commodity devices where cost was the major decision criteria, but, more importantly, a large number were chosen because the foreign product was the only component available for a specific technology.[10]

b. Mechanical/Structural

Mechanical components of the two missiles include the airframe, wings and fins, safe/arm devices, inertial reference unit and the radome. Each of these components is critical for the proper functioning of the missile. The JSPO for AMRAAM was aware of only a single case of offshore sourcing, the actuator motors. These components are multiple sourced, from Globe and Clifton Precision in the U.S. and Lucas Aerospace in the U.K. Cost was the decisive factor driving part of the procurement offshore. The actual contract quantities allotted to each manufacturer have varied from lot to lot, with cost as the sole selection factor.

The primary offshore sourcing issue for this mechanical/structural area is raw materials. The stainless steel of the safe/arm device requires chromium mined in South Africa. The wings and fins are manufactured from titanium mined in Australia. In some cases new sources, which are not now economically viable, could be tapped, such as titanium sands in Florida. In other cases however, there is no substitution possible, for example, stainless steel cannot be made without chromium, and South Africa is by far the dominant supplier. Corning makes the radome for AMRAAM for both Hughes and Raytheon from a material known as Pyroceram. Magnesite is required to make radome and is procured from Mexico.

With the decline of the domestic numerically controlled machine tool industry, a significant issue for the manufacturers of mechanical components is how to procure the processing tools required. The highest-precision automated cutting tools are

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9 "Industrial Preparedness Study: Sparrow AIM/RIM 7M Mobilization," Lowell, MA: Raytheon Missile Systems Division, p. 6-8.

10 "Industrial Preparedness Study: Sparrow AIM/RIM 7M Mobilization," Lowell, MA: Raytheon Missile Systems Division, p. B-10.

often manufactured offshore. At prime-contractor Hughes, 80 percent by value of its production machining equipment for AMRAAM is Japanese. This equipment is required to produce the missile housing, fins and wings, and electronics chassis. Hughes management stated flatly that U.S. vendors could not supply tools which would routinely maintain the levels of precision required for the manufacture of the missile, and estimated that it would take three to five years to qualify a domestic supplier. At M/A-Com, all production steps for the RF head are carried out in the U.S., but 100 percent of the tooling for precision machining is of Japanese origin. The quality of the Japanese machines is the deciding factor in this case also. In performing the Sparrow mobilization study, Raytheon concluded that to increase the capacity of the fabrication facility for mechanical components would require 26 new machine tools at a cost of $9.4 million, of which 10 would be of Japanese origin.

Other than its requirement for the stainless steel, the safe/arm device does not have a foreign source difficulty. All manufacturing is performed domestically on U.S. equipment. At least one manufacturer holds a definite bias against use of foreign production tools and processes. As a result, the firm has taken steps to ensure that its parts and tools remain U.S.-sourced.

c. Chemical

Chemical technology is a factor in three major components of the two missile systems: the warhead, the rocket motor, and the batteries. The warhead is made entirely of U.S. materials processed in the U.S. The warhead supplier has no foreign sourcing, but complains of scheduling delays because of domestic sole-source suppliers.

The rocket motor has two areas involving foreign sourcing. First, the motor requires two constituent chemicals sourced from offshore. Isophorone diisocynate (IPDI) is sold domestically by Thorson Chemical Corporation but is manufactured in Germany by Huls. The key reason for its offshore production is that a chemical intermediate is phosgene gas, production of which is outlawed under U.S. environmental law. The other chemical component is hydroxy-terminated polybutadiene (HTPB), manufactured in the U.S. by Sartomer. This company was recently purchased by Atochem, a French concern. Current production capacity remains in the U.S. However there are indications that Atochem will construct a plant to manufacture HTPB in France.

Second, one critical production machine, a flow-form machine to produce the motor cases, is purchased from Lifeld, a West German company. The reason for the purchase was not immediately known; most likely it was economic. Similar

machines are available from U.S. manufacturers, so it appears that a dependence on foreign technology is minor, as long as current U.S. sources remain viable.

D. CONCLUSIONS AND RECOMMENDATIONS

The foreign situation does not appear to place the U.S. in an immediately vulnerable situation for either the AMRAAM or Sparrow programs. The most significant technology-related foreign-source dependencies identified appear common to most systems with substantial microelectronic subsystems—commodity semiconductors, ceramic packages, and advanced gallium arsenide (GaAs) materials. To the extent that short-term supply distributions could be anticipated, stockpiling materials such as chromium and titanium and some semiconductors seems a feasible solution, but ceramic packaging and GaAs appear to have significant technical limitations. Past obstacles to development of domestic production capabilities have been less related to U.S. access to ceramic and GaAs technologies, than to the smaller market developed for them in the U.S. than in Japan. Greater market interest here caused the technology momentum to migrate to Japan and to provide the base for a now-dominant world-market position. Since Japan is believed now to out-invest the U.S. rather heavily in ceramics and gallium arsenide, establishment of economically viable domestic commercial production would likely be a costly and probably lengthy process, but not technologically insurmountable. The same applied to semiconductor packaging and testing, which economic, not technology considerations, have attracted offshore.

The other area of concern involved microelectronic production equipment and machine tools, especially numerically controlled and precision equipment. In these areas, there appear to be growing indications of of technological advantage shifting to foreign competitors, particularly Japanese companies.

ANNEX IV
HEAVY COMBAT VEHICLE ENGINES

A. INTRODUCTION

Heavy combat vehicle engines were investigated because they represent a critical mechanical system used widely by DoD. The three engines chosen were the AGT-1500, the LV100, and the XAV28:

- the AGT-1500 is the gas turbine engine used to power the M1A1 Main Battle Tank;
- the AGT-1500 is built by Textron Lycoming;
- the LV100 and the XAV28 are being developed under the Advanced Integrated Propulsion System (AIPS) Program;
- AIPS engines are being developed for use in future tank and other heavy armored vehicles;
- the LV100 gas turbine engine is being developed by General Electric and Textron Lycoming; and
- the XAVB28 is a 1500 HP diesel engine being developed by the Cummins Engine Company.

B. METHODOLOGY

Visits were made to the tank engine program offices at the U.S. Army Tank and Automotive Command (TACOM) in Detroit, and to each of the engine's prime contractors facilities. Technical discussions were held with the design staff to identify where foreign technology was incorporated into the engines, why it had been incorporated, and what subsystems and components might incorporate foreign parts. On-site surveys were conducted to identify the extent of foreign dependence on producer manufacturing processes and equipment.

C. FINDINGS

1. System Foreign Sourcing

Analysis of the M1A1 engine (the AGT-1500) and the two AIPS engines (the LV100 gas turbine and the XA28 1500HP diesel) identified limited use of foreign sourced components and technologies. Table II.9 provides a summary of findings of foreign dependence for the tank engine programs analyzed.

Table II.9
SUMMARY OF FINDINGS FROM STUDIES—TANK ENGINES

Part/Component	Assembly	Foreign Sources	Reason for Sourcing	Alternatives	Reasons for Delay
AGT-1500	**Textron Lycoming**				
Machine Tools	Milling, turning, grinding	FRG, France, Italy, Japan, U.K., Swiss.	Cost, delivery, quality, service, availability	Indefinite	Development of technology base
LV100	**GE-Textro**				
Recuperator	Engine	FRG	Quality/reliability/$	2 + years	Development and quality testing
Low-Pressure Turbine	Engine	FRG	Schedule/$	2 + years	Development
Air Filter	Engine	FRG	Quality/reliability/$	2 + years	Development and quality testing
Machine Tools	Same as AGT-1500	FRG, Japan, etc.	Cost, etc.	Indefinite	Development of technology base
XAV2B	**Cummins Eng. Co.**				
Injector Solenoid	Engine	Japan	Cost	1 + year	Install production tooling
Head Bolts	Engine	FRG	Cost	No delay	N/A
Machine Tools	Same as AGT-1500	FRG, Japan, etc.	Cost, etc.	Indefinite	Development of technology base

a. AGT-1500

No foreign sourcing of parts or subsystems was found for the current AGT-1500 at the prime level, or at subtier levels. However, production is increasingly dependent on foreign-sourced machine tools.

b. LV100 Gas Turbine Engine

The LV100 incorporates foreign-designed and manufactured subsystems in three areas:

- recuperator (MTU, West Germany);
- low-pressure turbine (MTU, West Germany); and
- powerpack cooling system (MTU, West Germany).

MTU is building the recuperator because it proposed a superior engineering design. MTU's low-pressure turbine incorporates state-of-the-art technology, comparable to that available in the United States, in its design and associated manufacturing processes. The MTU cooling system design was selected as part of the teaming agreement and not for technology reasons.

c. XAV28 1500 HP Diesel Engine

The XAV28 1500 HP diesel engine incorporates two foreign-made parts in the development program engine:

- a fuel injector solenoid produced in Japan; and
- a head bolt produced in Europe.

In both cases, the reason for using a foreign source was cost. In the case of the solenoid, the one American supplier that bid on the procurement required $750,000 for the necessary tooling to provide the development program quantities. The Japanese firm agreed to redesign a similar commercial solenoid to meet Cummins requirements at no cost and to bear any tooling modification costs required. The foreign-supplied head bolt represents a savings of over $3000 per engine. There is no unique technology involved in either case.

d. AIPS Foreign Sourcing Policy

The AIPS program stipulates that the contractor is free to use any source for parts during the development phase but that domestic sources must be used during the production phase. TACOM personnel said that they did not want to restrict

contractors in selecting technology that could be used during the development program, or to force them to buy from a domestic supplier if a lower-cost foreign supplier was available. The contracts are fixed price, so costs in excess of TACOM funding are borne by the contractors. TACOM personnel emphasized however that they would enforce a "Buy-American" clause for the production contract. AIPS contractors must have agreements with U.S.-based manufacturers (either domestic or foreign-owned) that will be able to produce the parts during the production phase. Implicit in this approach is that the volume of Heavy Force Modernization program vehicle procurement will justify the investments required for dedicated production facilities in the U.S. However, with budget cuts and decreasing need for conventional forces in Europe, this assumption and policy may eventually require revision.

2. Foreign Sourcing—Machine Tools

According to the manufacturing engineering staffs at GE, Textron Lycoming, and Cummins, foreign suppliers now dominate the U.S. market for high-end milling, boring, grinding and turning machine tools. This includes broaching and non-conventional drilling machines, multi-axis numerically controlled (NC) machine tools and machining centers, parallel-axis gear grinders, and jig grinding and boring machines. The U.S. tank and AIPS engine manufacturers stated that they are buying the foreign machine tools for the following reasons, in roughly this order of importance:

- only source available;
- higher quality (hold better tolerances, greater repeatability);
- lower cost;
- shorter delivery schedules;
- more responsive to requirements;
- better service; and
- faster delivery of spare parts.

Textron Lycoming recently completed a major ($26 million) five-year equipment modernization program. Analysis of the purchases made under that plan showed:

- imported machine tools accounted for almost 45 percent of the $26 million spent on modernization;

- the average value of the foreign machine tools purchased was $179,000 versus an average $41,000 for the domestic machine tools purchased, reflecting foreign dominance of the high-end equipment; and

- even after this multi-year machine tool modernization program, 66 percent of its tools were 25 years old or more.

Manufacturers also state that many parts of U.S.-labeled machines are manufactured offshore and assembled in the United States.

CHAPTER III
FOREIGN VULNERABILITY OF CRITICAL INDUSTRIES

A. STUDY OBJECTIVES AND CONTENTS

This chapter summarizes a study effort by The Analytic Sciences Corporation (TASC)[1] that focused on foreign vulnerability in advanced manufacturing process technologies. Three case studies examine competitive positions, foreign vulnerabilities, and options available to strengthen domestic capability in the industries that build numerically controlled (NC) machine tool controllers, NC machining centers, and electronic test equipment. TASC developed and applied a quantitative methodology to assess degrees of foreign vulnerability, formulated general and specific conclusions, and developed conclusions based on the findings.

This study arises from the need to develop a coherent Government response to the foreign dependence problem. First, it addresses the need to gather evidence on the scope and nature of foreign dependence. A key objective of this study has been to consolidate information on foreign dependence that has been previously extracted from databases or in special studies. It also adds to the knowledge base by including new case studies that identify potential foreign vulnerabilities for selected process technologies that are critical to DoD. (Section C summarizes the case studies. Appendix B to this report contains summaries of the prior studies.)

Second, the study addresses the need to distinguish between foreign dependencies that pose little or no threat to the national security and those that could have critical national security impacts. Because there is a large (and growing) number of dependencies, not all of which are amenable to solution by DoD, criteria are needed to assess the degree of vulnerability and establish rough priorities for action. A key objective of this study has been to develop specific criteria for measuring the degree of vulnerability caused by foreign source dependencies. It also tests these vulnerability criteria by applying them to the case studies. Section B describes the methodology used, while the results of its application are described in Section C.

Finally, the study addresses the need to identify actions that can be taken by DoD (and, more specifically, by DARPA) to help solve foreign dependence problems—by remedying current dependencies and avoiding future dependencies, and

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1 J. Gansler, L. Lembo, J. Stam, D. Leech, D. Dobeasky, and C. Neckyfarow.

by avoiding *ad hoc,* ineffective responses. The study addresses generic solutions as well as more specific and detailed actions that can decrease or eliminate vulnerabilities in the areas described in the case studies. Section D discusses potential solutions to foreign vulnerability problems, considers their feasibility and utility, and highlights those that may represent especially promising areas for DoD and DARPA. Summary conclusions and recommendations are in Section E.

B. ASSESSING VULNERABILITY

1. Methodology Overview

A primary objective of this study is to develop a quantitative measure of foreign vulnerability that will enable DARPA to establish priorities for action. The quantitative assessment is supported and complemented by a qualitative analysis, to assure that all factors that bear on vulnerability are taken into account. The methodology is based on a two-stage process. First, a qualitative assessment of the criticality of an industry was performed, using criteria that had been developed through earlier work in this area. (Examples of criteria are essentiality, linkages, and substitutability.) Second, a quantitative assessment of foreign vulnerability was performed in areas that were found to be critical. This quantitative assessment was based on the Herfindahl-Hirschman Index (HHI), a numerical measure of market concentration that is described below. This two-stage process is depicted in Figure III.1.

2. Criteria for Determining Industry Criticality

Existing foreign dependence data show that dependencies are widespread and affect a mix of "low-tech" and "high-tech" goods. Although this reinforces DoD's need to give attention to diverse products and industries, there are also benefits to specifying "critical industries" that are particularly important to DoD (and the economic security of the nation at large). Frequently, these do not involve current dependencies but are areas where foreign sourcing is extensive and a future foreign dependence is threatened. Identifying "critical industries" permits DoD to identify capabilities that are essential to maintain onshore and areas where early Government action is required. Clearly, the nation cannot support complete production capabilities for all products and technologies required for the national defense. For some dependencies, robust domestic capabilities are essential, while in others, offshore dependencies may be tolerated or even encouraged. Criteria must therefore be applied to determine the degree of vulnerability. The criteria weigh such factors as the essentiality of a product or industry, the likelihood that access to the product may be interrupted, and the impact that loss of the product or industrial capability might have on the economy or operational readiness.

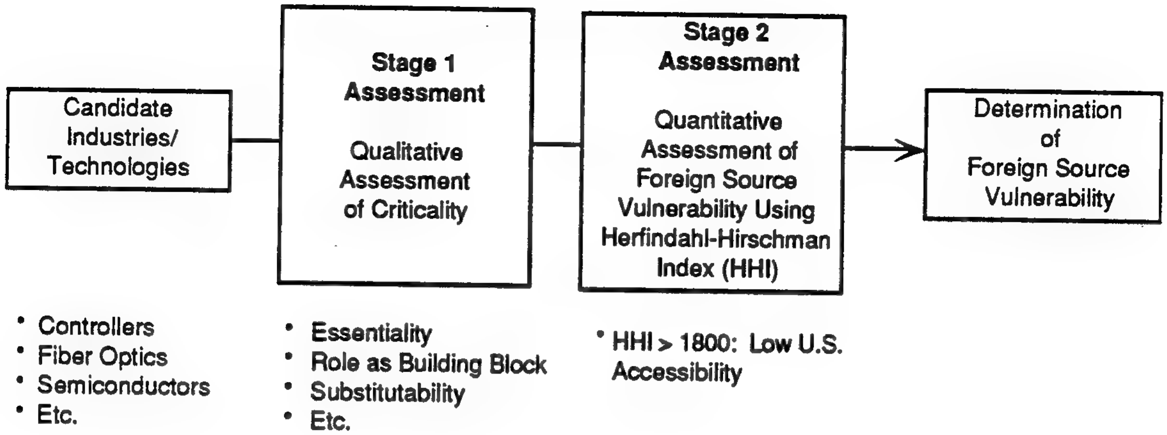

Figure III.1
STUDY METHODOLOGY

Foreign vulnerability is not determined by any one factor, but usually by several, acting in combination. The selection of technology areas for the case studies took into account a number of measures of an industry's criticality. One set of criteria, developed for the U.S.D(A) report, "Bolstering Defense Industrial Competitiveness," considers the need to maintain an acceptable level of U.S. international competitiveness as well as to avoid adverse national security impacts. They give emphasis to the fact that the significance of an industry cannot be judged in isolation, but must be interpreted in the context of its linkages to other important segments of the industrial base. These factors describe a critical industry as one that produces essential products, supports (or is supported by) other critical industries that are important to maintain, and has high barriers to entry that make it difficult to change the *status quo*.

Among the specific factors that must be considered in weighing whether an industry is critical is its essentiality; its ability to be reconstituted once lost; the ease with which the knowhow embodied in an industry can be diffused; the rate of technological change and R&D expenditures; linkages between one industry and others; spillover benefits, in which the loss of one capability would damage or lead to the loss of others; and industry structure, which permits or precludes the entry of

alternative suppliers. Other criticality factors include stockpileability, substitutability, and market and geographic concentration.

Vulnerability factors were also examined in a 1983 research study that developed a methodology for assessing vulnerability to non-fuel mineral supply problems.[2] Based on an extensive survey of the literature, the authors identified 23 factors, which were divided into four categories. The first category, location, takes into account distance of sources, concentration of sources, and shipping exposure. The second category includes political and market factors, such as monopolization, supplier independence, trade and investment restrictions, ideological tension, supplier instability, and denial of access. The third category is called strength. Individual factors are size of U.S. industry, size of U.S. reserves and resources, stockpile insufficiency, limited processing capability, and poor equipment. The final and largest category is U.S. flexibility. These factors consider alternative approaches such as substitution, reallocation, and recycling/recovery. They also weigh whether materials are necessary in combination with other materials, as well as R&D, regulatory costs, business costs, plant expansion lag, and surge capacity. In addition to identifying these criteria, the study used a Delphi approach to assess which factors were the most important determinants of vulnerability. The experts who participated in the study overwhelmingly weighted concentration of sources (normally associated with level of imports) as the most important. Denial of access was the second most heavily weighted factor, with all others considered much less important.

Applying the criticality criteria described above, we have identified the industrial controller, electronic test equipment, and NC machine tool industries as meeting the criteria and therefore as being examples of critical sectors. While these are of course not the only industries that could have been selected, we believe that they clearly meet the criticality criteria and serve as a manageable and reasonably representative group for inclusion as case studies.

3. Vulnerability Assessment Approach

The vulnerability assessment methodology described below represents an "ideal" approach that presumes that all required data can be obtained. While those data requirements are not extreme, most are not readily available from published sources and the time frame of this study was too short to develop independent

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2 K. Myers, "U.S. Vulnerability to Non-Fuel Mineral Supply Problems," *Journal of Resource Management and Technology, 12,* 3(1983), 177-189.

sources. As a result, we were unable to apply all elements of the methodology in the case studies. Although data on changes in market share and R&D expenditures (both current and over time) were unavailable, the qualitative assessment takes a number of dynamic factors into account, and we believe that the absence of time series and R&D data has had only a limited impact on the policy recommendations in each case study area. Where possible, case studies include static (one year) quantitative assessments of "dependence," "geopolitical risk," and "entry barriers." These measures are described below.

a. Conceptual Approach

Our approach to vulnerability assessment is grounded in economic theory and, before describing the methodology in detail, it is important to understand its conceptual basis and key assumptions. Economists describe the competitive nature of industries by using measures of market concentration. A long empirical tradition has established a high correlation between high levels of market concentration and the ability of producers to increase profits by effectively limiting entry by competing firms. This contention underlies the industry analyses that are regularly performed by the U.S. Department of Justice and the U.S. Federal Trade Commission in antitrust cases. The empirical evidence also supports a contention that is extremely important to the analysis of foreign vulnerability: that market outcomes (for example, availability or denial of access) can be predicted on the basis of market indicators (such as the distribution of firms' market shares.) This is the basic hypothesis for the quantitative analysis of national security vulnerability.[3]

There are two significant differences between antitrust-related analysis and this vulnerability analysis. First, the correlation between market structure and profitability is directly relevant to the chief concern of antitrust. But in the context of foreign vulnerability, the correlation between market structure and profitability provides only indirect verification of the ability of firms (or groups of firms) to exercise market power that would deny market access to buyers.[4] In the national security case, the

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3 A similar hypothesis underlies recent work in this area by Theodore Moran. However, that analysis uses the "4/50 rule," which is a simpler measure of concentration than the HHI. See Moran's "The Globalization of America's Defense Industries: What is the Threat? How Can It Be Managed? Guidelines for a New Generation of Defense Industrial Strategists" (1989), (unpublished).

4 It is interesting to note that the measure of market structure we rely on—the Herfindahl-Hirschman Index—is rooted in a theory about the conditions necessary for effective collusion among firms. See, for example, George Stigler, "A Theory of Oligopoly," reprinted in *The Organization of Industry*, ed., G. Stigler, Homewood, Ill., Irwin, (1968).

buyer is attempting to purchase (and, failing that, produce) a material, component, or manufacturing technology in support of national security requirements. If markets are accessible, a buyer can expect to find suppliers willing and able to sell. Even in situations where existing firms are unwilling to sell in the desired quantities, markets are accessible if there are no significant legal, economic, or technological barriers that prevent potential suppliers from converting resources currently devoted to the production of similar products to the production of the products in question.

Another important difference between standard antitrust analysis and vulnerability analysis is that, in vulnerability analysis, the geographic location of firms' production facilities is an important factor in determining a market's accessibility. For example, an international industry may appear to be non-competitive, but if market power is exercised by firms located in the U.S., then inaccessibility and vulnerability are not considered to be problems. Conversely, if an international industry has the characteristics of a competitive market, but the distribution is skewed toward very few foreign nations, the market could be considered highly inaccessible or vulnerable. Thus, the methodology for the vulnerability assessment takes into account national affiliation as well as the more traditional measures of market concentration that are used in antitrust.

b. Herfindahl-Hirschman Index (HHI)

The measure of market structure used in the vulnerability assessment is the Herfindahl-Hirschman Index (HHI).[5] The HHI is calculated by summing the squares of the market shares of individual firms in a market. The HHI gives proportionally greater weight to larger market shares to reflect their relatively greater market power. Consequently, the HHI is not just a measure of market concentration, but takes into account the more significant impacts of market share distribution. At its extremes, the HHI approaches zero (that is, highly competitive) if the market consists of a very large number of firms. There would be no danger of vulnerability. The HHI approaches 10,000 as the number of firms approaches one (with a market share of 100 percent). This market would be non-competitive and excessively vulnerable.

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5 For a complete discussion of the theoretical, empirical, and practical aspects of the HHI, see J. E. Kwoka, "The Herfindahl Index in Theory and Practice," *The Antitrust Bulletin*, Winter 1985; and P. A. Pautler, "A Guide to the Herfindahl Index for Antitrust Attorneys," *Research in Law and Economics*, Vol. 5, 1983.

An advantage of using this approach is that the HHI is widely accepted by industry analysts as an indicator of market performance, and is therefore backed by both empirical evidence and analytic tradition.[6] The Department of Justice, for example, divides the spectrum of potential market power measured by the HHI as follows:

- HHI < 1000 = effectively competitive (high accessibility);
- 1000 < HHI < 1800 = moderate market power (moderate accessibility); and
- HHI > 1800 = high levels of market power (low accessibility).

Although there is some flexibility in interpreting HHI thresholds, our approach uses the above categories adopted by the Department of Justice as indicators of foreign vulnerability risk.[7] The interpretation of these categories for the purposes of the foreign vulnerability assessment are as follows:

- An HHI of 1000 or less indicates that the market is relatively secure and the likelihood of disruption is low.

- An HHI of 1800 or more (with no prominent U.S. or Canadian producers) indicates a vulnerable market, since high concentration gives strong market power to current suppliers and restricts the potential for access by new suppliers.

- The results are not immediately conclusive with HHIs between 1000 and 1800. In these cases, the second step of our quantitative vulnerability assessment—probing the rate and direction of change in the HHI (described below)—is especially important.

c. "Static" Quantitative Assessment

The first step in our assessment provides snapshots of current vulnerability. The assessment is based on three measures of vulnerability that are calculated using the HHI and different groupings of market share.

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6 The U.S. Department of Justice, for example, uses the HHI in its "Antitrust Enforcement Guidelines for International Operations," (1988), as an indicator of the degree of competition resulting from merger activity.

7 As will be shown in the case study assessments, a higher threshold than that used by DOJ may be more appropriate to measuring foreign vulnerability risk. Additional research into threshold levels would appear to be necessary.

- First, we calculate a "geopolitical index" by grouping market shares by nation of origin. This measures U.S. vulnerability to the denial of critical products by foreign nations. It addresses the risk that the U.S. will be unable to obtain a sufficient supply because of such factors as denial or technology delay. (The denial or delay could be attributed to geopolitical collusion, economic warfare, natural or manmade disaster, or disruption of transportation networks, for example. Technology delay could reflect an intentional decision to withhold technology or a lack of priority given to the needs of U.S. buyers.) U.S. firms' international market shares are excluded from the calculation, since the intent is to assess the danger of collusion and other forms of denial by another nation or nations. Supplies from the U.S. are assumed to be reliable.

- The second is a "foreign dependence index." This measures the extent of U.S. dependence on foreign nations, highlighting U.S. reliance on only a few foreign nations for its supply of a commodity. The index is derived by grouping international producers' U.S. market shares by nation and excluding the U.S. share of the domestic market from the calculation.

- The third index is the "entry barrier" index. This measures the extent to which production is concentrated in only a few firms worldwide. It indicates the ease with which new suppliers can enter the market if an expansion of the existing industrial base is required. Barriers to entry could result in an inability to adequately expand domestic production, if critical products were denied by foreign sources. This quantitative assessment is derived from individual firms' (U.S. and foreign) international market shares.

d. "Dynamic" Quantitative Assessment

The second step in the "ideal" foreign vulnerability assessment examines the dynamics of market share. It measures the rate and direction of change, in order to identify trends that may lead to greater or lesser vulnerability in the future. This part of the assessment is also based on the HHI index. As noted above, data on R&D expenditures and trends in market share were not available to the project team because of the short time frame for the study and were therefore not included in this analysis.

The first of the quantitative indicators is the change in the HHI for market share over the past five years. The ability or inability of new firms to garner market share is a good indicator of the actual accessibility of the market and the future direction of the industry. A primary use of this measure is to "fine-tune" the assessment for

industries falling in the 1000 to 1800 HHI category. If there are no significant U.S. or Canadian producers, a gain of over 100 HHI points in the last five years might be reason to consider these industries as candidates for policy action.

The second indicator of the rate and direction of market accessibility is the rate at which firms are advancing the key performance characteristics of their products—in other words, the rate of technological change within the industry. The use of this measure is premised on the notion that rapid advances in firms' ability to improve the performance of their products will lead changes in market share. This is also measured over a five year period and provides supporting data for the assessment of future market conditions.

e. Qualitative Assessment

Quantitative measurements such as the HHI have the advantage of being systematic, unbiased, and applicable to a wide range of industries and products. However, a single measure cannot take into account all of the considerations that bear on vulnerability and the national priorities that may impinge on a decision to take action to resolve a foreign dependence problem. The indices are useful in screening and setting priorities, but additional analysis is required to draw definitive conclusions. The foreign dependence assessments (Section C) therefore provide a qualitative assessment of foreign vulnerability in order to complement and amplify the quantitative analysis and support the development of specific recommendations for action.

f. Policy Options

The fourth step in the approach identifies Government actions for industrial markets found to be vulnerable in the quantitative and qualitative assessments. The goal is to identify a hierarchy of markets deserving varying levels of public policy attention. (Although this report includes case studies of only three technologies, the methodology can obviously be applied to a wide range of potential dependencies and vulnerabilities.) The categories for action are as follows:

- Highest Priority Policy Treatment
  - HHI > 1800
  - 1000 < HHI < 1800; five year change in market share > +100 HHI

- Second Priority Policy Treatment
  - 1000 < HHI < 1800
  - HHI > 1800; five year change in market share is negative

- Low Priority Policy Treatment
  - -- 1000 < HHI < 1800; change in market share is negative
  - -- HHI < 1000

In developing action plans for vulnerable industries, DARPA's challenge lies in choosing legitimate and high-priority candidates for assistance and supporting these industries in ways that are consistent with broad U.S. policy and its own mission. The development of the policy options will, wherever possible, be closely aligned with the competitive strategies that are being pursued by industry, in order to leverage those strategies and ensure the convergence of public and private objectives. This part of the effort will involve:

- identifying the nature and causes of competitive advantage in the industry;
- identifying actions that are being taken by U.S. firms to maintain or bolster their strategic positions;
- identifying the specific objectives of a Government/industry strategy to reduce vulnerability; and
- identifying Government actions that could meet the desired objectives, with a goal of complementing firms' competitive strategies where possible.

Although many of the causes of and solutions to foreign dependence problems are beyond DARPA's control, there are a number of areas where DARPA-led policies and programs can have a positive impact on our foreign dependence problems. Section D contains a discussion of available tools and mechanisms, while Section C describes specific actions that can be taken to reduce vulnerabilities in the case study areas.

C. FOREIGN DEPENDENCE ASSESSMENTS

1. Case Study Background

a. Introduction

The case studies assess the nation's foreign vulnerability for three important process technologies that meet the criticality criteria described in Section B. The first two relate to modern machine tools (controllers and numerically controlled machining centers), and the third is electronic test equipment. These items were selected as example cases because of their importance to defense and the

widespread perception that their vulnerability could potentially threaten national security. The Defense Manufacturing Board recently stated that:

> Using linkage and foreign dependence as criteria, industry observers have amassed...short lists of critical sectors—semiconductors, computers, advanced materials, and *machine tools.*[8]

In addition, a recent DARPA survey of defense prime and subcontractors (see Chapter II) found that production equipment is a major source of dependence and that our vulnerability is of great concern to defense contractors, who require this equipment to produce nearly all defense systems and components.[9]

The case studies show the complexity of assessing the degree to which an eroding market constitutes vulnerability and determining whether targeted Government programs to support an industry are necessary or desirable. The assessment is less ambiguous in cases of total foreign dependence, where there is no domestic capability to meet defense needs and the cutoff of foreign sources would leave the U.S. with no alternative supply. In these situations, vulnerability is judged primarily on the basis of the diversity and reliability of the foreign suppliers.

The results of the assessment are more ambiguous when a diminishing market share poses a potential threat to the national security, but there are still viable domestic producers capable of expanding, if necessary, to meet defense needs. The questions are: "How much market penetration is acceptable? When does that penetration begin to endanger our national security? And how much domestic capacity is enough?" There are no firm answers. The case studies therefore provide "best estimates" on the extent and impact of vulnerabilities and the importance of remedial action by the government.

The following "quick-look" analyses assess DoD's vulnerability to foreign sources of supply by examining key market factors and trends:

- the changing nature of technology;
- major buyer groups and their changing needs;

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8 See "Policy Issues for the Defense Industrial Strategy Task Force," (undated Defense Manufacturing Board issue paper).

9 Institute for Defense Analysis, "U.S. Defense System Dependence on Foreign Technology," Final Report Briefing, December 1989.

- major suppliers and the distribution of their market shares;
- past and present strategies pursued by major suppliers; and
- the impact of trends in each of these areas on national security vulnerability.

b. Machine Tool Industry

Historically, the U.S. had a strong and innovative machine tool industry that held a leadership position in the worldwide marketplace. Although there were numerous foreign competitors, particularly in West Germany, the U.S. industry was preeminent in domestic markets and a viable force worldwide. However, the industry is now suffering the effects of competition from abroad and its future health cannot be assured. The causes and impacts of the decline of the industry are well known, due to a 1982 petition by Houdaille Industries that requested import relief on the basis of unfair trade practices by Japan, and a subsequent National Machine Tool Builders Association (NMTBA) petition to the Department of Justice that requested import relief on national security grounds.

The Houdaille petition asked the Government to suspend the investment tax credit for Japanese-made computerized machine tools, under the authority of Section 103 of the Revenue Act of 1971. The Government denied the petition after a year's deliberation. The NMTBA petition was filed on the basis of Section 232 of the Trade Expansion Act of 1962, and claimed that an import-caused injury jeopardized an industry that is essential to defense production. The final decision was that the machine tool industry was sufficiently important to the national defense to warrant Government intervention and Voluntary Restraint Agreements (VRAs) with major producing nations (Japan, West Germany, Taiwan, and Switzerland) were announced in May of 1986. The VRAs covered four categories of machine tools that accounted for about 79 percent of the total value of U.S. machine tool imports. In addition to these import restrictions, a domestic action plan was developed to provide the industry with information on DoD requirements, strengthen U.S. industry involvement with DoD research in manufacturing technology, increase Government support of machine tool R&D, and otherwise enhance domestic competitiveness.

These actions, which have been in effect since 1986, have not positively resolved the industry's problems, which are in some respects worsening. The first two cases analyzed below examine the level of vulnerability associated with two particularly troubled segments of the industry, and recommend additional actions that can be taken to improve their vitality. The third case study examines a closely related industry that is facing the same competitive pressures as machine tool producers.

Despite the acknowledged magnitude of the industry's problems, the U.S. is not strictly dependent on foreign nations for machine tools and related products. Domestic capacity for a full range of machine tools currently exists and the United States is still considered by some to be the world leader in the production of specialized, advanced technology machines. But as the Department of Justice's affirmative response to the NMTBA petition showed, national security is nevertheless vulnerable to the decline of our domestic capability over the last decade and the threat that our capability might further diminish in the future. The petition justified this national security damage on the grounds that the industry could not meet the nation's needs for machine tools in a mobilization or war, when demand would escalate quickly and foreign supplies could be cut off. (The NMTBA estimates that approximately 20 percent of U.S. consumption of machine tools is for defense purposes during peacetime, and that wartime demand can increase defense consumption six to eight times.) In addition to this concern about the industry's ability to meet wartime needs, a viable domestic machine tool industry, offering a full line of products and services, is essential to maintaining a healthy peacetime defense base.

c. Industry Characteristics

Although the machine tool industry's problems arise from a variety of sources, the structure of the industry and the cyclical demand for its products have left the industry ill-equipped to meet the competitive pressures of the last decade. Despite the strategic significance and visibility of the industry, it is relatively small in size, and the size of individual firms within the industry has also tended to be small. These small U.S. companies are unable to conduct new product development programs to the extent that their larger international competitors do, and so are steadily becoming less competitive. The problems are exacerbated by the fact that the industry is highly cyclical and risky—machine tools are long-lived and purchases can be easily postponed during economic downturns. The sensitivity of the market to economic conditions has resulted in irregular profits, undercapitalization, and limited cash flow for new product R&D, which the NMTBA petition called the "lifeblood of the machine tool business." One estimate is that the industry's investment in R&D has traditionally been well under 2 percent of sales[10]—much less than required to maintain parity in innovation with aggressive foreign competitors.

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10 D. Rapkin, "Industrial Policy and Trade Conflict in the Machine Tool Industry: The Houdaille Case," (1983), p. 19 (unpublished).

To guard against developing excess capacity that would be idled during periodic downturns, the U.S. industry adopted the practice of producing machines one at a time, rather than moving toward a standardized product and assembly line manufacturing methods that could lower costs, speed delivery times, and achieve economies of scale. Slow productivity growth has been compounded by a tendency to fire skilled workers during economic downturns, and then rehire and retrain workers as demand rises. As a result, most of the U.S. machine tool industry is trying to compete in sales of modern, flexible automation equipment using aging facilities populated largely by manual equipment, an untrained or aging workforce, and obsolete or inefficient manufacturing methods. As reported by a Department of Commerce study, "Traditionally, the machine tool industry has been among the last to adopt the technology it develops and produces for others."[11]

d. Growth of Competition

The U.S. industry had been weakened through its fragmented structure and poor strategic choices, but an important opening for foreign competition was a technology that was first developed in the U.S.—numerical control (NC). The first NC machine was developed and demonstrated in 1952 under the sponsorship of the U.S. Air Force, which was concerned with improved methods for machining complex structures for airframes, but the new technology was not diffused widely to other defense and commercial sectors until the mid-1960s. Computer numerical control systems appeared in 1973 and commanded the field by 1979. Since that time, CNC has become an integral part of the revolution in production technologies through industrial automation approaches such as computer assisted design (CAD), computer assisted manufacturing (CAM), flexible manufacturing systems (FMS), and computer integrated manufacturing (CIM).

While U.S. industry was relatively slow to expand product lines to meet the burgeoning demand for NC and CNC machines, the centrally directed Japanese machine tool industry capitalized on the shift to numerical control and rapidly built up an industrial capability to produce these machines. The Japanese focused on two particular products: NC lathes and NC machining centers. MITI's industrial policies to develop NC and CNC capabilities were implemented through three Extraordinary Measures Laws that paralleled the key developments within the

11 U.S. Department of Commerce, "Machine Tools and Accessories," *U.S. Industrial Outlook,* 1983.

industry: the first Law covers machinery, the second covers both machinery and electronics, and the third includes machinery and information industries.[12]

Although the first Extraordinary Measures Law was enacted in 1956, the huge growth in Japanese capability did not occur until the 1970s, when the government's targeting actions were specifically directed at NC. The objectives of the new strategy were to provide increased R&D funding to the Japanese machine tool industry and to make NC tools available to a wide range of Japanese businesses. MITI attempted to rationalize the industry by encouraging firms to abandon smaller and less profitable product lines and to concentrate instead on numerically controlled machines, with a goal of over 50 percent NC by 1982. Other actions taken by MITI included the authorization of an export cartel, government funding for joint research, special depreciation allowances, and state sponsored/cooperative research.[13]

The industry-government partnership forged in Japan during the 1970s was extraordinarily successful in penetrating world markets for NC tools. The Japanese share of the U.S. market for NC machine tools grew from less than 5 percent in 1976 to over 50 percent in 1982; in 1981, one out of every two CNC lathes sold in the West was made in Japan; and, by 1986, two-thirds of all NC machine tools used in the U.S. were imported, most of these from Japan.[14] It is important to note that NC machines—most supplied by Japan—are particularly critical to defense applications, which require extreme precision and close tolerances. By 1986, Japan was the world's largest producer of machine tools, with an industry comprising 250 firms with productivity and capitalization well in excess of their U.S. counterparts.[15]

The modern Japanese machine tool industry differs from the U.S. industry in fundamental ways. One key to Japan's success is product standardization. Japan's tools embody relatively simple technology, enabling Japanese firms to use

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12 R. Sarathy, "The Interplay of Industrial Policy and International Strategy: Japan's Machine Tool Industry," *California Management Review,* Spring 1989, p. 139.

13 R. Sarathy, "The Interplay of Industrial Policy and International Strategy: Japan's Machine Tool Industry," *California Management Review,* Spring 1989, p. 139.

14 R. Sarathy, "The Interplay of Industrial Policy and International Strategy: Japan's Machine Tool Industry," *California Management Review,* Spring 1989, p. 133.

15 R. Sarathy, "The Interplay of Industrial Policy and International Strategy: Japan's Machine Tool Industry," *California Management Review,* Spring 1989, p. 142.

high-volume, assembly-line production methods. This reduces costs, improves productivity, shortens leadtimes, and eases worldwide distribution. Japanese firms have been oriented toward a growing population of small- and medium-sized buyers, who are attracted by the flexibility, ready availability, and low price of the Japanese tools. These buyers purchase simpler, off-the shelf products, while U.S. firms continue to be oriented toward more traditional customers who require customized or "dedicated" tools.

During the 1970s and early 1980s, fluctuations in the world economy and shifts in machine tool demand also worked to the benefit of Japanese firms, who were recipients of their government's support and were therefore able to remain viable during downturns. U.S. industry began its decline after peaking in 1967, and was further weakened when the industry experienced a general recession in the early- to mid-1970s. A strong growth in U.S. demand in the late-1970s both strapped the capabilities of U.S. producers and increased the attractiveness of the U.S. import market to foreign producers, who had also suffered from the recession. There was considerable Japanese import penetration between 1975 and 1980. The weakened U.S. industry responded to demand growth by increasing its backlogs and lengthening lead-times, while Japanese firms were able to fill orders quickly with standardized tools that were being held in inventory in Japan, Europe, and across the U.S.

When the industry was hit with another general recession in 1982-1983, U.S. firms were forced to cut back operations—new orders received by domestic machine tool builders fell 84 percent between 1980 and 1983. At the same time, the inventories of Japanese machine tools in the U.S. were sustained, only to be sold at reduced prices and attractive terms when demand revived. This allowed the Japanese to capture additional market share by supplying new customers from inventory at prices and terms that could not be matched by domestic competitors. The U.S. lost its designation as the world's largest producer of machine tools to Japan in 1982, and was fourth behind Japan, the Soviet Union, and West Germany in 1983. The U.S. share of world machine tool exports was 21 percent in 1964, but the share had fallen to 4.6 percent in 1983 as the U.S. found itself in sixth place behind West Germany, Japan, Italy, Switzerland, and East Germany.[16]

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16 National Machine Tool Builders' Association, "Petition (to the U.S. Department of Commerce) Under the National Security Clause, Section 232 of the Trade Expansion Act of 1962 (19 U.S.C. 1862), For Adjustment of Imports of Machine Tools," 1982.

e. Current Market Conditions

Recently, the domestic market has undergone another shift, with a growing Japanese manufacturing presence onshore. To solidify their market share and to position for future product lines such as Flexible Manufacturing Systems, a number of Japanese firms have set up U.S. subsidiaries and other firms have agreed to set up joint ventures in the U.S. In still other cases, Japanese firms have established a domestic presence through sales and servicing networks for their products.[17]

At present, the U.S. industry is still eroding with respect to its competitors. The U.S. still has machine tool capacity, but there is no doubt that our capability is declining, and that Voluntary Restraint Agreements (VRAs) have done little to reverse the trend. The number of manufacturing facilities has decreased from 1,394 in 1982 to 652 in 1987.[18] This time period also saw a decline in employment, from 77,800 in 1982 to 46,400 in 1987, as the import share of our national consumption increased from under 40 percent to nearly 58 percent.[19] Although the U.S. retains its reputation as the world leader for some highly advanced machine tools, it lags in areas of R&D that are crucial to leadership in tomorrow's market. Domestic R&D emphasis is strongly on military applications, artificial intelligence, and software prototyping tools. The U.S. significantly lags Japan in design and industrial application of flexible automation, robotics, and controls. The capability of the U.S. is generally considered to be on a par with its European competitors, but our competitiveness is diminishing in certain areas of machine tools, controls, and robotics. Compared to our international competitors, there is little domestic R&D in such key technologies as industrial controls, manufacturing applications of flexible automation, and industrial robotics for flexible automation products.

There has been a slight reduction in imports of some types of machine tools since voluntary restraints were imposed in 1986. However, imports have continued play a major role in the domestic market. Import's share of the domestic consumption of metal cutting tools has increased from 55 percent in 1986 to 59 percent in 1989; imports of metal forming tools have only decreased from 58 percent to

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17 R. Sarathy, "The Interplay of Industrial Policy and International Strategy: Japan's Machine Tool Industry," *California Management Review*, Spring 1989, p. 153.

18 National Machine Tool Builders, *The Economic Handbook of Machine Tool Industry, 1989-90*, p. 62.

19 National Machine Tool Builders, *The Economic Handbook of Machine Tool Industry, 1989-90*, p.62.

54 percent over the same period; and imports of all NC machines have only decreased from 60 percent to 58 percent. Overall, machine tool imports increased from 56 percent to 58 percent between 1986 and 1989, despite the presence of VRAs.[20]

It is clear that trends in the machine tool industry as a whole indicate a real and even greater potential foreign vulnerability. However, an analysis of vulnerability is more appropriately performed for a class of products than for an entire industry, which can be extremely diverse. The next two sections analyze two specific machine tool products in depth: NC machining centers, which constitute an end item produced by the machine tool industry, and microprocessor controls for CNC machines, which are produced by distinct segments of the machine tool or electronics industries. The third case examines a related product, electronic test equipment.

2. Case 1: Controllers

a. Controller Technology

Controllers are considered essential to the nation because they provide the brains of all modern automation equipment and represent the area of greatest potential for increasing the capability of machine tools in the future. There is a widespread belief within the manufacturing community that there is a growing vulnerability for controllers for computer numerically controlled machine tools. The potential dependence of U.S. industry (and especially the defense industry) on foreign controllers is believed to be extremely serious, since the flexibility, cost, quality, and leadtimes for manufacturing operations are increasingly dependent on advanced machines and the controllers that manage the process.

Today's market offers a variety of controllers with a wide range of capabilities, but DoD is most interested in top-end controllers, which provide the high degree of precision and extreme tolerances that are required for critical defense applications. More capable controllers use advanced processor chips and software languages and tools to command and control multiple axes of motion to relatively high accuracies at relatively high speeds. Processing speed and sequencing are extremely

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20 National Machine Tool Builders Association, "Import Penetration of the U.S. Machine Tool Market," Statistical Report No. 110-89, August 30, 1989, p.4. The import values are adjusted to include freight, commissions, and other import-related charges. The 1988 data are preliminary and the 1989 data are First Quarter 1989 data annualized. Department of Commerce data.

important because of the number of applications being run simultaneously and the need to routinely provide motion control instructions on a millisecond or faster basis. A typical high-end controller plans, coordinates, and controls the actions of all machines and mechanisms in a workstation. Typical controller actions may include machining, machine setup, intra-workstation materials handling and part inspection, grasping, and fixturing, as well as such functions as task planning and process programming. The controller's workstation functions are supported by a knowledge base that could include such information as workstation capabilities and operations; product definition data; and manufacturing policies and procedures. Controllers tend to be highly differentiated and there is a large amount of variation in the capabilities offered and the way that these functions are realized. The preponderance of different types of controllers has led one observer to cite the "Tower of Babel" on the factory floor, and eventually may lead to the development of a more standardized product.

Technically, high-end CNC controllers are becoming increasingly capable. Many users claim that today's technology does not begin to provide the performance they require, in effect creating a perpetual market for better and better machines. Processing speed has made simultaneous multi-axis control possible for fairly high-speed motion in all controlled axes. Support in the controller of graphical programming and high-level languages is allowing more and more functions previously done in manufacturing engineering offices to be done on (or by) the controller. All of these advances contribute enormously to increased productivity and higher, more repeatable quality, which give users of these machines a competitive edge.

b. User Segments

The controller market is relatively narrow—as of 1983, only four industrial sectors accounted for 90 percent of the numerically controlled equipment currently installed in the U.S[21]. The market also has two discrete components. In the first, controllers are sold directly to machine tool users for use in retrofits, refurbishments, or upgrading of equipment to make it compatible with other equipment in the plant. In the second component, called the "captive" segment, controllers are used by machine tool builders (original equipment manufacturers [OEMs]) to outfit the new NC machine tools that they produce. Some of the most important OEMs produce their own CNCs for installation on their own equipment. Because the volume of controllers sold or transferred internally is sometimes insufficient to support

21 These industrial sectors include SIC code industries 34-37.

a viable controller development and support operation, some machine tool builders have enlarged their controller market by expanding from the captive segment into direct sales. The difficulties faced by these suppliers is enhanced by the substantial losses that many have experienced in their low-end, high-volume, revenue-generating product lines.

Size is another distinguishing characteristic of controller buyers. Large machine tool consumers have in many ways driven the nature of controller technology—for example, with their recent pressure on controller manufacturers to move toward open architectures. Small machine shops, which produce 65 to 75 percent of the discrete parts manufactured in U.S, also form an important part of the market. Significantly, many of these small machine shops are part of the subtier networks of major manufacturers. It is widely believed that the loss of a large portion of U.S. market share is due to the fact that domestic producers did not pay sufficient attention to the technical needs of small users. At the same time, the Japanese industry leader (Fanuc) achieved its success by targeting the needs of this large market segment and producing controllers for reliable, easy-to-operate, and low-cost machine tools.

Today's controller industry is driven by rapidly changing user needs. Among these are:

- Factory integration and the push to better integrate a diverse inventory of machine tools into manufacturing cells. Industry experts predict that in the near future manufacturing cells will produce 90 percent of all discrete parts made in the U.S.

- Access to controller source codes and development of controllers with open architectures in order to facilitate integration. Although there are no open architecture controllers on today's market, at least two firms are reported to be willing to license source codes in response to growing demands by major manufacturing firms.

- Manufacturing automation protocol (MAP), endorsed by major manufacturers in the early 1980s to help standardize communications among programmable equipment. Industry analysts predict that MAP will lead to an industry standard for CNC controllers.

- Sensor-based control for robots and machine tools, which reinforces the need for an open architecture and also places new demands on the functionality and performance of controller operations.

- Utilization of CNC technologies as a means of introducing modern manufacturing strategies (for example concurrent engineering, statistical process control, and just-in-time inventory systems.) To reach this goal, factory-floor integration must be extended from the prime contractors to subtier suppliers of manufactured piece-parts, who will be required to have analogous capabilities. For example, subtier producers might be required to install coordinate measurement machines—a new area of application for controllers—in order to certify compliance with statistical process control standards.

These trends underscore the need, from the users' perspective, to effectively reduce the plethora of different controllers, as well as the need for access to producers' source codes or a standard open system architecture.

c. Today's Market

As the above discussion shows, the controller industry is highly dynamic, with many future market opportunities. But historically, the domestic controller industry has experienced even greater difficulty with foreign penetration than the machine tool industry. The largest Japanese producer, Fanuc, quickly established market dominance with a product line of microprocessor-based controllers that was relatively inexpensive as well as simple to program, while U.S. producers were slow to move into new controller technologies. The Japanese firms also benefited from Japan's extensive industrial targeting initiatives in the NC/CNC machine tool field, which built up both a strong machine tool industry and an unparalleled machine tool base.

Over the past 10 years, the primary Japanese controller manufacturers have steadily increased the performance of their top-end controllers, as have European manufacturers. U.S. producers have been less than successful in keeping up with their Japanese and European counterparts. There are relatively few serious domestic competitors, and their market is almost entirely domestic. Modern controllers are extremely expensive to design, test, and introduce, and their installation must still be tailored to some degree for each different machine. With a current share of approximately 30 percent of the U.S. market and only about 8 percent worldwide, the industry claims it has insufficient revenue to keep pace with the foreign competition—and particularly with the industry leader, Fanuc. As a result, some U.S. firms have left the market and another major producer, who entered into a joint venture with Fanuc, is now a marketing and limited manufacturing arm for Fanuc-designed CNCs. Although U.S. manufacturers are known to produce fully capable high-end controllers, none of the U.S. suppliers can be considered a major player in the worldwide market.

With the changes in today's market, the controller industry finds itself in transition. Producers are haunted by the hard-learned lesson of Fanuc's amazing market success: pay closer attention to users' needs. At the same time, the increasing demand for source code access and open controller architectures threatens to homogenize their products, thereby undercutting sources of competitive advantage. The advantages that would accrue to early entrants in the new marketplace could be significant, but the risks of throwing away the source of product differentiation are also high. Some analysts believe that if major foreign firms are first to supply open architectures to U.S. buyers, they will succeed in undercutting the high-end niche markets of domestic producers in a manner reminiscent of their success in the low-end markets.

d. Industry Strategies

Controller suppliers could adopt a number of different strategies to capitalize on present-day market opportunities. Among non-captive controller producers, four strategies can be identified:[22]

- The joint venture strategy (as followed by GE-Fanuc), which combines the low-cost manufacturing capabilities of offshore suppliers with the systems analysis and software strengths of domestic producers. These latter strengths will be crucial to satisfying the needs of major users as they attempt to integrate their production operations. Fanuc's major success to date has been among smaller users of low-end controllers. The GE-Fanuc venture was intended, in part, to provide the Japanese with greater high-end and system integration market access.

- To capitalize on expected market growth, focus on providing the machine tool segment of the domestic customer base with CNC retrofit packages, as the major users attempt to integrate their factory floors and those of their subtiers'. Firms adopting this strategy will put off R&D investments in open architectures, opting instead to augment their systems integration capabilities.

22 These strategies were identified by controller producers who participated in the survey for this study.

- Emphasize entry into foreign markets and give less attention to the domestic market. Since firms adopting this strategy will inevitably run into problems with trade barriers and entrenched foreign suppliers, they will continue to pursue the domestic retrofit market and the potential market for new CNC applications.

- Provide source codes to tool builders and users, and develop open architecture controllers that rely on hardened PC platforms. Firms adopting this strategy are betting heavily on the future demand for CNC systems (for example cells) and on the potential for new applications as CNC is "let out of the box."

Captive controller producers face a different set of problems in formulating strategy. Their strategic investments entail difficult choices between advancing machine tool hardware and advancing controller capabilities, and especially controller software. Three possible strategies for captive producers are:

- Abandon captive CNC controller production and adopt the controllers of firms that provide source code access. This will free up corporate resources to develop machine tool hardware and/or to augment systems integration capabilities.

- Turn off shore for hardware development and attempt to retain differentiated "closed" controller designs.

- Combine systems integration capability with standard PC-based controller software and standardized modular machine tool hardware. Firms adopting this low-cost strategy stand to compete effectively even in the market segments most recently dominated by foreign firms. It is widely believed that foreign firms are at a competitive disadvantage in applications where system integration and user-friendly software development are stressed, since these require supplying users adequate applications and software support.

e. Vulnerability Assessment: Geopolitical Index

There are a fairly large number of captive and non-captive producers of controllers throughout the world, but capabilities differ considerably. Table III.1 provides a representative list of major producers, along with their national affiliation. Many "captive" suppliers in the U.S. are included on the list.

Table III.1
INTERNATIONAL CONTROLLER SUPPLIERS

Allen Bradley (U.S)	Yasakawa (Japan)	Dynapath (U.S.)
Fanuc (GE) (Japan/U.S.)	Philips (Netherlands)	Cincinnatti-Milacron (U.S.)
Siemens (West Germany)	Num (France)	Kearney & Trecker (U.S.)
Mitsubishi (Japan)	Heidenhain (W. Germany)	Giddings & Lewis (U.S.)
Okuma (Japan)	Bosch (W. Germany)	WCI (U.S.)
Fidel (U.S.)		

As an initial measure of vulnerability, firms were grouped by nation to construct a geopolitical index. The index assumes that national governments can exercise effective control over firms within their borders, and in effect cause firms to act in a collusive fashion to deny a product to the U.S. This would be much less likely to occur if numerous firms were to act on their own, without national direction. As an example, all firms within a nation could become involved in a boycott or economic denial action. Similarly, firms within a national border would be more likely to be jointly affected by such factors as internal strife, disaster, or transportation disruption. The geopolitical index therefore shows that vulnerability is greater if sources are concentrated in one nation, and that vulnerability is less severe if firms are distributed worldwide.

Table III.2 shows the ranking of nations by shares of free world controller sales or transfers to original equipment manufacturers (OEMs). It also shows the square of the market share for each nation. The sum of these figures gives the value of the HHI index, which was described in detail in Section B).

As indicated by Table III.2, the HHI index for the worldwide distribution of market share by nation is 290. Based on a threshold of 1800, the controller market is clearly one where the risk of vulnerability appears to be significant and demands further analysis. The index level reflects the high concentration of market power in Japan and in West Germany, which together comprise 70 percent of the world market. In contrast, domestic producers possess little market share outside the U.S.—only 8 percent worldwide.

Table III.2
NATIONS' SHARES OF FREE WORLD CONTROLLER SALES AND TRANSFERS TO OEMs

Nation	Share	Share of Non-U.S. Share
Japan	49%	2401
West Germany	21%	441
United States	8%	--
Italy	4%	16
United Kingdom	3%	9
France	3%	9
South Korea	3%	9
Taiwan	3%	9
Switzerland	2%	4
Spain	1%	1
Peoples Republic of China	1%	1
Canada	1%	1
South America	1%	1
Sweden	1%	1
HHI Index		2900

Japan has almost half of the worldwide market share alone and this dominance cannot be offset by the much smaller market shares held by other nations. If supplies from Japan were to become unavailable for any reason, worldwide availability of controllers would plummet. However, the more limited capability in other nations (including the U.S.) could potentially be expanded to make up for the loss of Japanese sources. The key variables would be the time and investment funding available to reconstitute or expand the capability that exists outside Japan. Interviews with U.S. producers have indicated that the primary constraint in expanding their capacity is economic, rather than a lack of capability for critical product and process technologies or other more insurmountable barriers. Reportedly, the technologies utilized in even the most advanced controllers are no more stressing than those required for other advanced commercial electronics products. Industry-wide, the U.S. also has strengths in the software technologies required for controller applications.

f. Vulnerability Assessment: Dependence Index

Table III.3 groups U.S. market shares by nation. In this context, the HHI can be interpreted as a straightforward measure of foreign dependence. The HHI indicates that somewhat less vulnerability is present when the domestic market rather than the worldwide market is considered, due to the fact that the U.S. retains a large proportion of the domestic market share. Domestic firms have 31 percent of the market, which is in part due to restrictions on purchases of foreign controllers for DoD. This sizeable market share indicates that our level of dependence may not be as great as popular belief might suggest. However, due to the need for capital investment and new product R&D, it is unclear whether the U.S. industry can remain viable if a further decline occurs. Regardless of the domestic share, the index is still in excess of the 1800 threshold, which indicates that we are highly dependent on foreign sources and that an unacceptable level of vulnerability could be present. Not surprisingly, Japan has the largest share of the domestic market, in addition to dominating the market worldwide.

Table III.3
NATIONAL SHARES OF CONTROLLER SALES AND TRANSFERS TO OEM PRODUCING IN THE U.S.

Nation	Share	Share
Japan	44%	1936
West Germany	7%	49
United States	31%	--
Other	12%	--
HHI Index		1985

g. Vulnerability Assessment: Entry Barrier Index

The HHI has also been calculated on the basis of the worldwide market shares of individual firms, without regard to national affiliation. This provides an indicator of the ease of entry into the market. The assumption is that individual firms with large market shares are able to reduce or eliminate the effects of competition by erecting barriers to entry. For example, new entrants may be unable to compete effectively because of proprietary technologies, excessive capital investment

requirements, or pre-established distribution systems. High barriers to entry suggest that difficulties could be encountered in efforts to reconstitute or expand production domestically if outside sources are blocked. Market share estimates for individual firms were provided to TASC by a leading U.S. producer under a nondisclosure agreement, and therefore are not enumerated in this report.

The HHI index based on individual market shares totals 2158. Since this value also exceeds the threshold value of 1800, high levels of vulnerability are indicated and further analysis of market structure is warranted. The index is driven over 1800 by the market share of Fanuc—the world's largest producer. Although some U.S. producers claim that their controllers achieve parity with Fanuc's, Fanuc controllers are widely considered to be the controller of choice within the industry. Fanuc was the early industry leader and has fully dominated the market since then.

h. Vulnerability Assessment: Qualitative Factors

Despite the high HHI values listed above, determining the level of vulnerability caused by the decline of the domestic controller industry is a complex. The market data analyzed in this case study clearly demonstrates that vulnerability exists. Vulnerability was indicated at all levels: by the Japanese dominance of the worldwide market at both the national and firm levels, by Japan's dominance in the domestic market, and by the domestic industry's minimal capability to perform effectively in world markets. However, the HHI analysis provides only an indicator of vulnerability and other real-world considerations must be weighed to determine whether the controller industry warrants the special attention of the Government. If one is solely concerned about the success of foreign nations in penetrating U.S. markets in the past, one is in danger of missing opportunities for leverage in the current market environment.

It is important to keep in mind the distinction between the vulnerability of a private enterprise caused by market forces and vulnerability that threatens national security. The first is a chiefly a private sector concern, while the second is a concern of both Government and industry. While there are clear indications that domestic suppliers are suffering from the effects of foreign competition, and may require outside assistance to meet competitive challenges successfully, it does not necessarily follow that DoD's continued access to controllers is similarly threatened. It is also important to note that the role of defense is to manage and adapt to changes in the industrial base over the long-run, rather than to forestall such changes through short-term actions. The context of the vulnerability analysis in this study is long-run. Industrial markets are highly dynamic. Vulnerability is assessed by looking into an uncertain future where requirements are unknown, cost constraints are arbitrary, and firms' technical offerings are rapidly changing—and

along with them, firms' ability to recapture, retain, or lose market position. Despite the fact that in each case the HHI values exceed threshold levels, there are other factors that mitigate against a simple determination that the nation's vulnerability for controllers is severe.

First, U.S. firms account for 31 percent of the domestic market for controllers, representing a significant pool of capacity and know-how that could be relied on to expand the industry if required.

Second, the nation has a large and generally underutilized stock of controllers that could meet a sharp increase in demand. Some observers believe that controllers may be even more underutilized than the machine tools they control.

Third, the likelihood of a supply cutoff or technology delay is mitigated by the significant degree of mutual interdependence between foreign controller producers and U.S. suppliers of microelectronics technologies. The major international controller producers rely on U.S.-designed microprocessors and a controller's software—representing some 75 to 80 percent of controller cost—is tightly bound to the choice of microprocessors. Neither nation would have the incentive to interrupt this relationship.

Fourth, U.S. firms maintain worldwide leadership positions in closely related technologies, which establishes firm linkages between controllers and other sectors. U.S. firms dominate the world market, for example, in programmable logic computers (PLCs) and in industrial computers (factory-hardened PCs). To the extent that these technologies are substitutes for, or technical alternatives to, many controller functions, a number of strong domestic firms may be capable of "entering the market" in an emergency setting where demand for controllers threaten to greatly exceed available supply.

Fifth, it is unlikely that the U.S. would be totally shut off from worldwide sources in the event of an emergency or a competitive failure of U.S. firms. Although there are advantages to maintaining an R&D base that will ensure that technologies of choice are available to DoD, foreign suppliers now provide full product lines that can (and could continue to) meet DoD's needs if a worst case were to come about. Although the dominance of Fanuc adds to the vulnerability of the international marketplace, the security of foreign sources is somewhat improved by the existence of a large number of competent (but smaller) firms located in allied nations.

Sixth, the nature of major CNC machine tool users' requirements—and therefore the direction of the controller market—is believed to be shifting in a direction

that plays to the competitive advantage of U.S. firms. Changes in user requirements are expected to include the following:

- A shift by major manufacturers to greater reliance on manufacturing cells that integrate a wide variety of stand-alone machines. This will require communicable controllers as well as systems integration capability and a degree of customer interface that is not readily available from foreign firms.

- A shift to modern manufacturing management methods, such as concurrent engineering (CE) and just-in-time (JIT) inventory control, is placing demands for new controller applications such as robotics, coordinate measuring, and continuous monitoring and automatic adjustment. These controller applications are currently dominated by domestic firms and require systems integration of the many small shops that constitute major manufacturers' subtiers. This could also provide domestic controller and machine tool producers the opportunity to regain some of the ground lost to Fanuc through its success with small machine-tool shops.

- An increasing user demand for open architecture controllers with standard interface languages. This represents a major opportunity for domestic firms. Some industry observers believe that Fanuc has less incentive to release its source codes (required for machine tool systems integration) due to its position as the standard in some applications. In addition to R&D that is financed by individual firms to augment their competitive postures, DoD and industry are funding programs, jointly and individually, which are aimed at creating technological capabilities that, if successfully adopted by the private sector, will bolster domestic industrial capabilities. The public-private National Center for Manufacturing Sciences (NCMS) is funding a multi-million dollar effort to develop a "next generation controller" that will have future payoffs for the industry. This new product flexibility could have a major impact on the controller marketplace.

i. Public Policy Options

The goal of the public policy options is for Government to assist industry in taking full advantage of competitive opportunities, and to pursue a more aggressive plan of action in the event that our domestic capability further diminishes. The following steps are consistent with the alternative industry strategies that were outlined earlier in this case study:

- The DoD could use its leverage as a buyer and regulator to encourage trends in manufacturing that serve the long-term interests of domestic machine tool controller producers. These actions, which could be implemented through various forms of incentives and tax policies, would also promote the modernization of the industrial base as a whole. Specifically DoD should explore ways to:

  -- Encourage the development and use of alternative controller technologies, especially industrial computers (factory environment hardened PCs), that are sources of U.S. competitive strength.

  -- Encourage the adaptation of alternative CNC manufacturing technologies where the U.S. has an opportunity to assume the leading edge, for example, CNC grinding, jet-water cutting, thermal cutting and coordinate measurement machining.

  -- Encourage the adaptation of cell technologies to increase the productivity of the machine tool base and bolster the controller retrofit market—again, areas of domestic competitive advantage.

  -- Encourage a recognition of the importance of the indirect costs of manufacturing as an important investment criteria, to promote the wider use of advanced manufacturing technology in U.S. industry.

  -- Encourage the widest possible adaptation of the manufacturing automation protocol (MAP).

  -- Encourage the flow-down of statistical process control requirements from prime contractors to their sub-tier machine shops, to open the small user market to U.S. manufacturers.

- Encourage, in whatever ways possible, the open architecture approach to controller technology. If domestic producers lag foreign producers in offering open-controller architectures to major users who are integrating their factory floors, domestic firms will forfeit whatever competitive advantages they now hold.

- The NCMS Next Generation Controller program has a high potential payoff for the industry. However, as with many other public-private initiatives, industry observers have expressed reservations about the program's chance of success. As a "high stakes" initiative, the Government should resolve industry's criticisms of the program and take any actions necessary to improve its effectiveness.

3. Case 2: Numerically Controlled (NC) Machining Centers

a. Machining Center Market

This case study assesses the vulnerability of NC machining centers, which are a specific class of NC machine tools that are particularly critical for defense applications. In 1988, aerospace and defense accounted for 19 percent of the revenues in the total machining center market. These tools are essential for machining special contour parts and components for weapon systems, and are able to machine other complex parts with greater precision and at tighter tolerances than other types of machines. At the same time, tool changeover and set up costs are minimized and material scrap and rework are reduced. As was the case with controllers, machining centers appear to warrant Government attention due to their strategic importance and the threat that import dominance poses domestic suppliers.

A machining center is a relatively new class of machine tool that can perform a number of different operations, such as milling, drilling, boring, facing, spotting, counterboring, threading, and tapping. It frequently performs these operations on four or more faces of a workpiece, in a single setup. Machining centers produce a complete (or nearly complete) part, without its having to be transported from machine to machine. NC machining centers have from three to five axes. Five axis machines, because of their wide use in aerospace and defense facilities, are generally thought to be the most strategically significant of the different types. Five-axis machines are commonly used for machining curved airframe structures and jet engine parts, such as impellers.

NC machining centers are one of two machine tool products that were targeted by Japan in the mid-1970s. (The other is NC lathes.) As a result, penetration of the domestic market for these machines over the past decade has been more severe than for most other types of machine tool products. Even though U.S.-made machining centers are among the most technologically advanced in the world, foreign producers account for over 57 percent of the machining centers used in the U.S. today. U.S. manufacturers are attracted to the Japanese-built tools for a variety of reasons. Many believe that foreign machining centers are lower in cost,

more reliable, have shorter leadtimes for delivery, and offer better service and maintenance than those produced in the U.S.

b. Market Share

There are many qualified domestic and foreign sources for machining centers—there are currently well over a hundred producers of machining centers in the international market, with the major producing countries being Japan, Italy, West Germany, the United States, the United Kingdom, and Switzerland. Despite the large number of sources, there is considerable concern about our foreign vulnerability for these items. The level of imports of NC machining centers increased phenomenally during the 1980s, as the use of these tools by a wide range of small- and medium-sized businesses grew. While the level of imports was only 21 percent in 1980, they had reached a high of 66 percent during 1986 and remained at 57 percent in 1988. The data also show increasing levels of Japanese market power; the Japanese worldwide market share reached 44 percent in 1988. This Japanese market share alone would yield an HHI index of 1936 (44 x 44), which is above the threshold of 1800 and which indicates disproportionate market power by Japanese firms. The HHI implies that action should be taken to reverse the decline of U.S. manufacturers and that close watch on the industry should be initiated to ensure that our current vulnerability does not worsen.

The decline in import share from 66 percent in 1986 to 57 percent by 1988 is in large measure explained by the 1986 Voluntary Restraint Agreement, which established limits on machining center imports. One estimate is that the VRAs decreased imports by 10 percent in their first year.[23] Another important factor in the reversal of the trend in import share was the continued decline of the dollar relative to the yen and European currencies, which contributed to an increase in U.S. machining center exports. Worth noting is the fact that imports from European nations, which were not bound formally by the restraints, appeared to have filled some of the void created by the Japanese adherence to the VRAs. Unfortunately, there are no indications that the import restraints have led to a recovery within the U.S. industry. The VRAs have not diminished the nation's concern about the dangerously high level of imports and the future of the domestic industry.

Historically, import penetration has been most significant at the lower end of the market, which is oriented toward commercial sector needs. Dependence is not

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23 J. McNolty, "Checking the Pulse of the U.S. Machining Center Market," *Manufacturing Engineering*, May 1988.

quite as significant in the aerospace industry, due to the fact that many of these applications require advanced technology machines. Five-axis machines—the "top of the line"—continue to be supplied primarily by domestic firms, and most are used in defense. Import penetration for five-axis machining centers reached only about 20 percent in 1985. These advanced tools comprise only a small part of the commercial market, but are used more extensively by DoD. Out of a total of 24,003 machining centers in the U.S. in 1983,[24] only about 1.5 percent had five axes. An overwhelming percentage (about 80 percent) of these five-axis tools were being utilized in strategic or defense-related operations. Twenty-two percent of the machining centers in the DIPEC inventory are five-axis, compared to the industry average of 1.5 percent.

The U.S. also leads domestically in providing machining centers for integration into flexible manufacturing systems, which utilize six or more machine tools under the control of a DNC computer. During 1988, more than 80 percent of the machining centers installed in FMS applications were built in the U.S. This new market is growing quickly and is also being targeted for growth by foreign competitors, who are beginning to establish facilities or capabilities within the U.S. to pursue these applications more aggressively.

c. Vulnerability Considerations

The "geopolitical" HHI Index described above indicates a high degree of vulnerability caused by a strong reliance on foreign supplies of machining centers. However, a number of other factors must be considered in determining the national security vulnerability posed by a diminishing domestic capability to produce these items. Two strengths of the U.S. industry that provide opportunities to grow market share in the future are as follows:

- Although the U.S. is at a competitive disadvantage both nationally and worldwide, it retains leadership in the advanced technology areas that are most important to DoD. Its weakness is at the low end of the market, which has been heavily targeted by the Japanese since the mid-1970s. Fortunately, these are not the items that are most critical to defense. The issue to be resolved is whether DoD wishes to maintain a domestic capability in "critical technology" niches, such as high-end machining centers, or will support an industry's full product line to retain its capability across the board.

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24 Data from *American Machinist Magazine's* 13th Inventory (1983).

- Despite the unprecedented success of the Japanese, there are indications that U.S. firms are meeting the competitive challenge. The U.S. machining center market is growing rapidly, due to manufacturers' need for improved flexibility. The area of greatest growth is the advanced machines and flexible manufacturing systems that are supplied predominantly by the U.S. At the same time, industry analysts believe that the "low-end" market will decline. Thus, the U.S. industry now finds itself at the forefront of a growing market for machines that offer improved flexibility and performance, while the Japanese market segment appears to be eroding.

These strengths are balanced by still other factors that need to be taken into account when weighing our foreign dependence vulnerability. First, today's domestic base—regardless of opportunities for the future—is insufficient to meet the nation's wartime needs. If the U.S. were to lose foreign sources of machining centers during a war or mobilization, it is doubtful that the U.S. could build enough machining centers to support increased weapons system production rates. The U.S. has the technical capabilities to build these products, but major capital investments and a strengthened base of supporting technologies would be required. Both would require long-leadtime actions.

Second, it is necessary to take into account the strength of supporting technologies and infrastructures—machining center manufacturers are the recipients of technology, rather than the forerunners of technology. For machine tools, supporting technologies and skills include castings, pattern makers, tool and die makers, and materials technologies. The U.S. still has an adequate base of casting manufacturers and materials technology, but is lacking in skilled personnel to make patterns and tools and dies. Each machining center also requires a controller, which in turn depends on capabilities in microelectronics, high speed servo motors, fiber optics technology and computer language development. In addition to the problems that are directly faced by domestic controller suppliers (see Case 1, above), the U.S. is losing ground in microelectronics and related technologies, which may lead to further erosion of the machining center segment of the machine tool industry.

d. Public Policy Options

Actions must be taken by suppliers, users, and the Government to assure that U.S. competitive strengths do not become diluted and that market thrusts do not become so fragmented that the "traditional" Japanese competitive strengths and methods enable them to dominate future growth markets, as they have in the past.

Specific Government-industry options for improving the future viability of the industry are:

- Foster cooperation (as opposed to collusion) between firms to develop a coordinated approach to market opportunities. Examples of potential actions include increasing product standardization and identifying common needs, such as those that are being pursued through the Next Generation Controller program.

- Provide greater direction to technological innovation. At the user end, U.S. industry has traditionally been the leader in producing new manufacturing technologies, but has been slow in adopting them. Modernization within the manufacturing base (both commercial and defense) would benefit both the producers of advanced technology equipment and the nation as a whole. At the supplier end, the industry could encourage such trends as FMSs for plastics and composites, which would increase machining center utilization.

- Build on the "lessons learned" from past industry efforts (for example Motorola) to enhance product R&D, quality, service, and cost competitiveness.

- Perform research in related areas (for example industrial controls technology, precision manufacturing technology, and sensors) with an aim toward focusing on market-driven applications of technology. A first step could be a cooperative industry effort to analyze the changing needs of domestic users.

- In order to hasten the technical maturity of new products, undertake Government-sponsored research in areas where the competitive arena requires rapid technological advancement.

- Initiate Government-industry efforts to pursue incremental innovation in areas where the technological frontier has diminished and emphasis has shifted to such issues as marketing, availability, and quality.

4. Case 4: Semiconductor Test Equipment

a. Uses of Microelectronic Test Equipment

Microelectronics test equipment is essential to the U.S. ability to meet military and economic objectives. This equipment is used to test integrated circuits (ICs),

which are required for many of the major subcomponents of military systems as well as for commercial products. Guidance systems, computers, avionic systems, command, control and communications systems, and electronic warfare systems all contain integrated circuits. A lack of test equipment—whether caused by denial by a foreign source or an inability to meet expanded mobilization or wartime needs—would prevent the U.S. from adequately screening its ICs. The inevitable result would be the use of malfunctioning ICs in critical items of military hardware, severely impacting the operational effectiveness of the nation's military forces.

The semiconductor industry has seen incredible growth over the last forty years, and is now a crucial part of the U.S. and world economies. Almost from the beginning, a separate Semiconductor Manufacturing Equipment (SME) industry was established to specialize in the complex and diverse equipment needed for the production, testing, and assembly of semiconductors and ICs. While firms in the controller and NC machining center industries produce goods that are required by a wide range of defense and commercial buyers, the SME industry is focused entirely on its "host" semiconductor industry. Consequently, the health of the two industries go hand in hand.

Different types of equipment have been designed to support the many processing steps in semiconductor production. Since much of the competition between firms, both domestic and foreign, takes place on the basis of proprietary or highly differentiated products that carry out particular functions, the industry places great emphasis on new product development.

The SME industry has three segments: wafer processing equipment, test equipment, and assembly equipment. Wafer processing refers to all procedures used to produce semiconductors or ICs. The materials technologies and processing methods used in this stage have undergone fundamental changes over the years. Some of the major steps involved are microlithography, deposit of thin film or epitaxial growth onto the wafer, etch/strip, inspection of mask and wafer, and doping. The second segment, testing, involves the detection of bad wafers or chips before processing continues and additional expense is incurred. As such, it is of significance in raising yields and improving productivity in semiconductor production. The third segment of the SME industry is assembly, which has undergone numerous productivity improvements through automation.

b. Automatic Test Equipment

As indicated above, SME is a diverse industry that offers a wide range of products. The analysis for this case study will be limited to one of the most important types of equipment produced by the industry: automatic test equipment. The

assessment includes all classes of automatic test equipment used for the testing of logic microelectronic circuits.

Automatic test equipment (ATE) hardware consists of a set of computer controlled electronic stimuli and measurement sensors, which are applied to each pin of the devices under test. The stimuli and the measurement systems can be switched back and forth, both among and between pins. They can also be switched to adapt to both parametric and functional test conditions. ATEs must be highly sophisticated machines, since they measure the logical activity of a multitude of elements contained in the internal workings of a chip.

In the 1970s, there were three types of testers: dedicated, general purpose, and bench top. With the increasing complexity of semiconductor and test technologies, new types of testers were required for different applications by the early 1980s: dedicated, focused, large-scale, and very-large scale. More recently, standards have been applied to testers to more closely relate the equipment terminology to the functions performed. Testers are now described by parameters such as pin count, channel rating, and frequency. In 1987, this methodology was formalized into an industry-wide test equipment ranking procedure, called the Maximum Data Channel Rate (MDCR) method. Classes of equipment range from 0 to 7, with 7 being the highest capability. The data on market share distribution presented below segments the various manufacturers' models by MCDR rating.

c. Market Share

Table III.4 lists the twenty major producers of ATE in the Free World market. Fourteen producers of automatic logic test equipment are in the United States, five are in Japan, and one is in Europe. While the U.S. has the greatest predominance of firms, most are small, and the Japanese companies command about a 44 percent share of the total world market. Siemens, the only producer outside the U.S. or Japan, has just .1 percent of the world market. The concentration of firms in the U.S. and Japan is not surprising, since this industry is tied very closely to semiconductor manufacturing, and equipment is produced in countries where chips are manufactured and tested. The industry has a relatively low degree of concentration. There is widespread technology know-how, low entry costs for plant and equipment, and economies of scale are relatively unimportant at a production level, since it is impractical to automate to a significant degree.

Table III.4 FREE WORLD PRODUCERS OF AUTOMATIC TEST EQUIPMENT	
Data I/O (U.S.) Datatron (U.S.) Eagle Test Systems (U.S.) Epro (U.S.) Exatron (U.S.) Gen Rad (U.S.) Megatest (U.S.) Advantest (Japan) Ando (Japan) Aisa Electronics (Japan)	Micro Component Technologies (U.S.) Pragmatic Test Systems (U.S.) Semiconductor Test Systems (U.S.) Sentry Schlumerger (U.S.) Textronix (U.S.) Teradyne (U.S.) Trillium (U.S.) Minato (Japan) Sarwa Radio (Japan) Siemens (Germany)

Although each nation's test equipment industry tends to serve its own semiconductor industry, U.S. manufacturers do purchase foreign-made microelectronics testers, primarily from Japan. A key reason is that the Japanese test equipment manufacturers have maintained tight linkages with the semiconductor industry and have been able to successfully anticipate its needs. The close relationship between semiconductor and manufacturing/test equipment producers is a key factor in competitive success.

Despite the somewhat rosy picture of U.S. industry that is painted by the large number of domestic firms and the nation's worldwide market share of over 50 percent, U.S. firms have been in a period of precipitous decline as the electronics industry has moved offshore. In 1983, the U.S. IC industry was hailed for its energy and entrepreneurship, but by 1986, the Japanese market share began to exceed that of the U.S. and the gap continues to widen today. As the domestic IC industry declined, the microelectronics test equipment industry also declined.

To provide a snapshot, Table III.5 shows 1986 worldwide sales and market share for different classes of test equipment, by company and nation. Japanese firms dominate the high end of the technology spectrum. The U.S. is not a competitor in this segment because it generally does not build the sophisticated chips that require such equipment. This increases our vulnerability at the high-end, assuming that the nation develops and retains a capability to produce sophisticated semiconductor products requiring testing devices that achieve high performance levels. Trends in the ATE industry indicate that adequate capability exists for most IC

applications, including CMOS and TTL. However, there are indications that equipment will not be developed quickly enough to support some types of GaAs circuits and other developing forms of microelectronics technologies. Advantest, a Japanese firm, is the world largest supplier of ATE in terms of total sales and quantities of testers by type. Its systems have recently been ranked as the best in the world and sales in the U.S. have been heavy, with Advantest systems utilized by large companies such as IBM and AT&T, as well as Government facilities.

Table III.5
WORLDWIDE MARKET SHARE IN THE LOGIC TEST MARKET ($M)

Company	Total	0	1	2	3	4	5	6	7
Advantest	107.3			6.5	6.5				
Ando	101.8				62.1		27.0	12.5	
Data I/O	.4								
Datatron	.7				.3				
Eagle Test	1.8			.5	1.3				
Epro	.5								
Exatron	.1								
Genrad	35.2						15.3		
LTX (Trillium)	22.0				22.0				
Megatest	30.3			2.3			28.0		
Micro Comp Test	10.7			10.7					
Pragmatic Test Sys.	.7								
Sanwa	1.6								
Semiconductor Test Sys.	3.3			.7	2.6				
Sentry Schlumber	99.2			25.6	56.7		16.9		
Siemens	.1								
Textronix	25.7				15.4				
Teradyne	21.2			1.2	20.0				
Tokyo Electron	6.0								
Other	4.5			.8	3.3				
Total	473.1	–	–	48.3	190.2	–	87.2	12.5	–

In the last 10 years, the U.S. market share has dropped from about 90 percent of the market to around 50 percent. In contrast, the Japanese market share has shown an increase from less than 10 percent 10 years ago to nearly half of the world market today. Japan's worldwide market share of 44 percent corresponds to an HHI index of 1936, which is above the 1800 threshold and sufficient to demonstrate a high level of market power by Japanese firms. The dominance is even

more striking when one considers that in 1981, Japan's market share of 26.1 percent yielded an HHI of only 676. Thus, the HHI has tripled in five years (1981-1985).

d. Vulnerability Considerations

Although the U.S. still holds a considerable share of the ATE market, the dramatic erosion of the U.S. market over the past ten years is a significant cause for concern. Three factors work to increase this concern. First, a healthy ATE industry (as well as ATE equipment itself) is essential to the health of the nation's microelectronics industrial base. At stake is not just one industry, but a broad range of industries that are important to both defense and the commercial sector. Another fact that contributes to national vulnerability is the concentration of production in only two nations of the world. If the U.S. capability were to further diminish and if the Japanese capability were to be denied for any reason, no alternative sources would be available to fill the need. A final area of concern is the Japanese dominance at the high end of the market, which could deny the U.S. the equipment it requires for advanced microelectronics applications.

An important determinant of the future competitiveness of the SME industry is its relationship with semiconductor manufacturers. A synergistic relationship enables the equipment industry to respond quickly to the changing needs of device-makers, driven by the continuous introduction of new products, requirements for increased mechanization of the production process to reduce contamination, and the desire for higher yields and increased productivity. In the U.S., the two industries have generally been kept separate and "proprietary" lines have been drawn, limiting communications on needs and solutions. In contrast, maintaining a synergistic relationship was a key factor in Japan's recent success in both areas. The close relationship between Japan's equipment and semiconductor industries allowed the equipment industry to follow in the footsteps of the semiconductor manufacturers during the latter industry's own phenomenal growth. Equipment manufacturers frequently operate as subsidiaries of Japan's large chip-making corporations, and the two industries view theirs as a "strategic relationship."

There are additional lessons to be learned from the Japanese success. The first involves changes in technology. The U.S. had maintained its lead when rapid "generational" changes—in both equipment and chip manufacturing—set up strong barriers to entry. However, later "incremental" advances allowed new Japanese firms to establish a foothold and increased the emphasis on factors such as cost and service. In addition, the Japanese pursued new technologies vigorously, while U.S. firms resisted "unnecessary" investment and continued their reliance on older generation technology and equipment. Still other factors that led to Japanese suc-

cess were implemented at the firm level. For one, the high cost of SME is in part due to on-site installation and servicing, which could be performed at less cost in Japan because of the equipment suppliers' "strategic relationship" with their key buyers. It was also possible for the Japanese to perform process and development work early to assure the performance of the product at the users' site.

e. Policy Options

These factors, in addition to greater attention to reliability, servicing, marketing, and R&D, enabled Japan to increase its market share at the expense of U.S. industry. Many of the policy options that are available for this industry would follow the Japanese model as a means of regaining market position. It is clearly necessary to promote greater cooperation between device-makers and equipment manufacturers—to create "strategic relationships" in the U.S. The equipment and semiconductor industries have already acknowledged this need and are taking independent actions to foster improved coordination. It is also important to promote increased R&D by ATE manufacturers, through both incentive programs and a continued Government commitment to SEMATECH, which could benefit the industry greatly. The industry would benefit from a private-sector commitment to increased R&D, based on an understanding of user needs and market-driven technology applications. Throughout, the Japanese model underscores the need to place greater emphasis on such factors as quality, service, and cost competitiveness, which will be crucial to future market success.

D. OPTIONS FOR REDUCING VULNERABILITY

1. Policy Framework

a. Spectrum of Foreign Vulnerability Solutions

Because of the diverse causes of foreign vulnerability, two forms of solutions are required. Generic solutions—which are in large measure outside DARPA's control—address the macroeconomic and institutional causes of foreign dependence and vulnerability. But it is also necessary to complement generic policy actions with solutions that are specifically tailored to the characteristics of an industry, its competitive environment, and the criticality of the industry's product(s) to defense and to the civilian economy. Because there is no universal cause of foreign dependence, there is no universal solution.

At one extreme, the correct solution may be to take no direct action to improve domestic capabilities and to tolerate a certain amount of dependence. This is consistent with the Government's policy of limiting intervention in the private sector

and, in fact, competitive pressures ultimately may result in improved industry performance without a strong Government role. Even with this approach, the degree of the vulnerability can be minimized by forging strong links with foreign sources of critical technologies, fostering research interchanges between foreign firms and private and governmental researchers in the U.S., establishing research contracts with foreign firms, encouraging joint ventures and licensing arrangements, and considering ways to induce foreign firms to locate R&D and other facilities in this country.

Another means for avoiding intrusive policy treatment is for the Government to follow an industry-led strategy. The cornerstone of this approach is that the concrete knowledge of industrial markets needed to formulate effective programs—and the responsibility for doing so—resides chiefly with industry. This "self-help" approach, which has received increasing support by both Government and industry, has the benefit of challenging industry to formulate credible strategic plans as a prerequisite for Government action. As a result, the industry has assumed direct responsibility for its eventual success or failure.

Under still other conditions, it may be found that significant Government investment and direction are required to retain or regain a critical national capability. This may be expressed as part of a broad industrial policy or as a targeted industry strategy. As an example of the breadth and depth of the possible actions that can be taken to affect an industry strategy, Table III.6[25] lists some of the steps taken by the Government of Japan to develop and expand its machine tool industry. This strategy led to a Japanese expansion from 13 percent of the non-Japanese world market for NC machine tools in 1975 to 50 percent of the market in 1981. The Japanese premise is that industry and Government must work together to develop high-technology industries. It is founded in the belief that market mechanisms are insufficient to ensure an adequate supply of and demand for new technology and that there are insufficient market returns for technology development. Although such a comprehensive and "intrusive" strategy may be unacceptable to the U.S. policy community, it does exemplify the broad range of actions that can be taken by a Government to improve the competitive position of a critical national industry.

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25 R. Sarathy, "The Interplay of Industrial Policy and International Strategy: Japan's Machine Tool Industry," *California Management Review*, Spring 1989, p. 141.

Table III.6
JAPANESE POLICIES FOR MACHINE TOOL INDUSTRY

Variable	Measures
Industry Structure	Rationalization, forced mergers
Product Line	NC tools 50 percent of market by 1980, manufacturing specialization, rules for disvestment of product lines
Customer Financing	Loans to small business, robot leasing authority, accelerated depreciation
Exports	MITI approved export cartel for machine tools
R&D	State-sponsored research, cooperative research cartels, contingency loans, R&D tax credits

This spectrum of solutions ranges from minimum levels of support to extensive intervention. The ability of a Government agency to implement an action or set of actions along the spectrum is in part determined by its industrial base mission and span of control. Many causes of foreign dependence and potential solutions are outside DARPA's scope of influence. For example, evidence shows that various fiscal and monetary policies have added to the growing domestic and international competitiveness problems. It also has been suggested that declining U.S. competitiveness has its root in institutionalized realities of the American system, such as our educational system, antitrust institutions, investment behavior, public support for R&D, and deteriorating infrastructure. While DARPA might add its voice to other concerns about macroeconomic policy and institutional practices, there is little opportunity for direct action on DARPA's part.

DARPA's challenge therefore lies in identifying legitimate and high-priority industries requiring assistance, and in selecting feasible solutions that are appropriate to the industry, within DARPA's span of control, and consistent with broader U.S. policy. Specific actions that can be taken to remedy foreign vulnerabilities in the case study areas were described in Section C. Since the foreign dependence problem is much broader than the three cases examined, this section reviews major categories of actions that are typically used by the Government to address foreign vulnerability problems.

b. Government Policies Affecting Foreign Vulnerability

It has been found repeatedly that inconsistent U.S. economic, industrial, and foreign policies contribute to the difficulty of implementing foreign dependence solutions.[26]

The first set of policies concerns the Government's role vis a vis the private sector. It is in the Government's interest to contribute to a strong and competitive U.S. industry, and its interest grows rapidly when industries are of crucial importance to defense. But this goal is tempered by a conviction that the Government's role is not to "subsidize" industries through targeted actions, but to support them through broad-based policies that benefit the nation as a whole. There is widespread confusion about what constitutes an appropriate industrial strategy, and what constitutes an intrusive and undesirable industrial policy. Thus, there is considerable Government concern about foreign vulnerability but little agreement on acceptable solutions.

The Government's policies with regard to trade with its allies also have objectives that can be incompatible with foreign dependence resolution. On the one hand, the Government seeks open trade to solidify relationships with its trading partners and to foster a competitive environment that enables it to purchase the best quality goods at the best price—regardless of origin. But it also acknowledges the need to restrict purchases to domestically produced goods when this proves necessary to maintain the peacetime and mobilization base required for defense. As examples of such conflicts in trade policy, "Buy America" restrictions have been the "first line of defense" in reducing foreign vulnerability. However, Buy America does not necessarily promote long-term competitiveness, because there is no assurance that domestic industry will use its profits to modernize or make other investments to enhance its competitive posture. Similarly, DoD's NATO rationalization, standardization, and interoperability policies encourage arms competition, in part through waivers of "Buy America" restrictions; foreign participation as subcontractors to U.S. primes; teaming, licensing, or subcontracting arrangements between firms of two or more nations; and NATO industrial participation in U.S. R&D projects. It also permits NATO contractors to compete for DoD procurements. The Competition in Contracting Act also has an impact on DoD's ability to balance domestic needs and international relationships. The Act gives priority to competition, while providing some exclusion to preserve mobilization capability. Clearly,

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26 Conflicting Government policies and regulations affecting foreign dependency are enumerated in "A Study of the Effect of Foreign Dependency: DoD Action Plan," ACC and TASC, 1986.

the conflicting objectives of these policies do little to promote a consistent and effective U.S. policy on reducing foreign dependence.

2. Categories of Action

Within this framework, the Government has taken steps to reduce foreign vulnerability for a variety of products and technologies, with wide-ranging results. Most often, these steps have constituted *ad hoc* actions rather than comprehensive industrial strategies with specific goals. As examples of what has and can be done, the following provides descriptions of selected instruments that are in use today.

a. Import Restrictions

Import restrictions are the action taken most frequently to protect domestic industries. Restrictions are imposed to establish or maintain a domestic production base; provide a surge or mobilization capability; reduce dependence on foreign sources; and provide temporary relief for troubled critical industries. Import restrictions can come about in a variety of ways. An industry can, for example, petition for relief under Section 232 of the Trade Act, which authorizes the Government to restrict imports in cases where the imports constitute a threat to the national security. Three recent Section 232 cases have involved machine tools (1986), antifriction bearings (1987), and plastic injection molding machinery (1988). Import restraints on numerous specific products have also been mandated by Congress or imposed unilaterally by DoD.

Generally, Congressional restrictions come about after private interests argue for legislative support for special protection, contending that they are injured by unfair or excessive imports. The constituents argue that domestic restrictions are needed to maintain the strength of the defense industrial base, avoid dependence on foreign sources, and protect jobs. The Congressionally mandated restrictions take the form of language in the DoD appropriations and authorization acts that prohibit the use of appropriated funds to purchase foreign products, limit DoD procurement from foreign sources, or limit procurement based on certain other conditions. DoD-imposed restrictions can have two sources. First, restrictions are imposed by the Secretary of Defense, following a determination that purchases must be made from domestic sources in order to meet industrial surge and mobilization requirements. Second, DoD Components can restrict imports by making a determination that uses Competition in Contracting Act procedures of "other than full and open competition" to establish or maintain an industrial mobilization base. These selectively restricted procurements make it possible to exclude foreign competition, but do not explicitly prohibit from buying from foreign sources.

Despite their wide use, import restrictions are generally considered to be ineffective in helping U.S. industry gain its competitive edge. The major concern is that protection does not give domestic firms the incentive to improve their competitiveness over the long run. The latter may well require long-range investment in plant and equipment or difficult management decisions that can be pushed aside when short-term profitability improves. A protected industry may well continue to produce a product that is inferior to a foreign-made alternative. Protection may remove competitive pressures, which may be the industry's primary incentive to modernize or otherwise enhance operations For these reasons, import restrictions are often imposed for only a limited time period and may also involve a compulsory industry "get well" program, such as the action plan developed for the machine tool industry. Another fundamental problem is that import restrictions most often target a final product, when the vulnerability actually may be caused by a shortfall in an intermediate step in the production chain. Thus, the underlying problem may be ignored. As an example, an industrial deficiency to produce precision bearings may be attributed to a lack of modern automated flexible manufacturing systems, rather than any problem that import restraints on the end product could resolve. For optics, the problem may be that industry is unwilling to make the needed investment in new equipment and processes. Short term import protection may not be sufficient to justify that investment.

b. Capacity Creation

While import restrictions are used when the capability to produce a product domestically is declining, the Defense Production Act Title III Program creates new capabilities as a means of eliminating foreign dependencies and reducing our vulnerability from foreign sourcing. Most of the products covered by import restrictions are mature and already in general use in DoD weapon systems. In contrast, Title III is building new capabilities in such advanced technology areas as polysilicon, single crystal silicon, silicon-on-insulator/silicon-on-sapphire, discontinuous reinforced aluminum, oxide dispersion strengthened sheet, high modulus pitch-based fiber, and ceramic bearings.

Typically, Title III creates capacity for advanced materials that may be available from foreign suppliers but are not widely available domestically. As an example, the U.S. has obtained all of its quartz fiber from a French firm, which was experiencing schedule slippages. The small amount of quartz fiber capacity in the U.S. was not considered commercially viable. With a Title III purchase guarantee, the domestic producer scaled up his operation and now has sufficient capacity to meet DoD needs. The fiber produced is 100 percent domestic, including domestically mined quartz. In another case, Title III is incentivizing the steel industry to develop a domestic capability for accelerated cooled, direct quenched (AC/DQ) steel, which

has many benefits over alternative forms. The AC/DQ technology originated in the U.S. but was never implemented domestically, and has been available only from Japan and European nations. The Title III project allows industry to "bring back" the technology through licensing arrangements with the Japanese.

The Title III program has a broad reach, since the Defense Production Act defines materials to include raw materials, articles, commodities, products, supplies, components, technical information, and processes. Requirements for Title III projects are identified by the Services through an annual "Project Call" or through long-range planning. The capacity established through Title III must be located in the U.S. or Canada, but foreign firms willing to create capacity in the U.S. are eligible for Title III awards.

Although the DPA authorizes the use of loans, loan guarantees, grants, and purchases/purchase commitments, a DoD agreement with OMB limits the current program to purchases/purchase commitments. In general, the Title III program purchases a limited amount of material to qualify the new source, and then commits to purchase the additional material if industry is unable to sell it on the open market. In the future, the use of a wider range of Title III incentives could increase the program's effectiveness in addressing foreign dependence issues. For example, loan guarantees could stimulate R&D in carefully selected areas of process, materials, and other critical technologies. Use of loan guarantees would act at the margin to channel additional investment resources in areas that are of importance to the national security community, partially redressing the advantages of foreign firms that have a much lower cost of capital than U.S. firms, and acting to stimulate research in these areas by private firms. Nevertheless, the "guaranteed market" that is currently provided through Title III has in many cases been shown to give industry sufficient incentive to make the investment necessary to compete effectively in new markets, and the program stands as one of the nation's most powerful tools for addressing foreign vulnerability issues.

Title III is not the only way that the Government can create domestic capacity to reduce the dangers of foreign dependence. Other options include directly subsidizing industry, establishing an independent production capability within Government facilities, or installing Government-owned equipment in contractor plants. These options have all been used to resolve capacity problems in the past, but would be considered low-priority in today's policy and fiscal environment.

c. R&D Initiatives

An adequate level of R&D investment is essential to reducing foreign dependence. As the National Research Council recently concluded, "competitive advan-

tage in international markets depends on continually operating near the technological frontier."[27] Unfortunately, foreign firms have significant advantages over domestic firms in generating the investment required to stay at the cutting edge. In Japanese defense-related industries, for example, the government provides direct subsidies and tax provisions, there is significantly less competition than in the U.S., there are no antitrust laws, and there is frequent joint research, product development, testing, and coordination of market share.[28] As a result of these and other factors, domestic firms are challenged by foreign product design advantages, global marketing superiority, government financial and tax aids, and fewer export restrictions. The National Research Council drew a direct connection between a successful export record and higher than average expenditure on R&D by an industry and its suppliers, which gives them a larger capital base with which to reinvest in R&D.

Within the U.S., Government-sponsored R&D has long been a favored means of assisting industry in maintaining the competitive edge in leading technologies. However, U.S. Government R&D investment falls short of what is required to maintain competitive industries. Among the many R&D programs in the Government today, the Manufacturing Technology (MANTECH) program is one that is directly oriented toward manufacturing R&D. It is clear that U.S. firms will need to upgrade manufacturing and product technology as foreign firms in Europe and Japan improve their competitive position through both product and integrated manufacturing technologies. Since the decline of critical process capabilities is a primary reason that the U.S. is becoming reliant on foreign sources, MANTECH and similar programs are a key element in reducing dependence.

In contrast to some foreign nations, DoD procurement policies and regulations are such that contractors are not incentivized to invest sufficiently in manufacturing technology development and implementation. Although the MANTECH program is designed to fill this gap, both industry and Government have tended to focus on short-term, low-risk projects rather than the major, strategic and innovative objectives that foreign competitors pursue. As a result, obsolete manufacturing processes are continuing to be used within the defense industry at the expense of increased costs, less affordable units, unreliable performance, and excessive scrap

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27 National Research Council's (NRC) Committee on Manufacturing Technology in Trade Adjustment Assistance, "The Role of Manufacturing Technology in Trade Adjustment Strategies."

28 Defense Science Board (DSB) Summer Study on the "Defense Industrial and Technology Base," 1988.

and rework. To increase the effectiveness of MANTECH in improving the modernization and competitiveness of U.S. industry, the National Academy of Sciences has recommended that MANTECH focus on generic issues with potential impact on more than one company, industry, or product, and use its funds as seed money to stimulate further contractor capital investment for modernization, process improvement, and use of computer-aided design, engineering, manufacturing resource planning, and just-in-time tools.[29]

d. Consortia

R&D deficiencies such as those described above prompted the U.S.' first consortia efforts. It had been found that since the Japanese and European governments subsidized numerous joint R&D projects, foreign competitors had access to much larger capital resources than were available to individual overseas U.S. firms. Among the factors leading to the larger availability of capital were the heavily-Government-funded, multi-billion-dollar research consortia (for example Esprit), subsidized production of favored projects in Europe and Japan, willingness of large vertically-integrated corporate structures to lose profits in order to gain market share, provision of long-term, low-interest capital by banks, and greater national savings and investment.[30] In order to give U.S. firms a tool that would enable them to complete, Congress passed the National Cooperative Research Act of 1984, which modified the antitrust laws for cooperative R&D, allowing firms to share costs, pool limited resources, compress time scales for development, reduce redundant effort, and thereby increase the total amount of R&D that can be undertaken. Legislation has also been developed to revise antitrust law to allow for joint production arrangements.

Since the passage of the law, a large number of consortia have been developed in the U.S., with varying success. One private consortia, U.S. Memories, has recently collapsed because it was unable to raise sufficient capital. This experience is viewed by many as an indicator of how difficult it will be for U.S. companies to focus on long-term strategy versus short-term profits, despite the need to cooperate with each other against foreign competition. On the other hand, SEMATECH, under DARPA sponsorship, is expected to contribute to the reduction of foreign

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29 National Academy of Sciences (NAS) Manufacturing Studies Board, "Manufacturing Technology: Cornerstone of a Renewed Defense Industrial Base," 1987.

30 American Electronics Association, National Center for Manufacturing Sciences, and Rebuild America, "Consortia and Capital: Industry-Led Policy in the 1990s," 1989.

dependence and vulnerability as well as improve the competitive posture of U.S. semiconductor producers.

There are a number of considerations that should be addressed by the Government in establishing and supporting future consortia. Government and industry roles and interests in these enterprises are very different. Industry must take the lead in commercialization, while the Government must take the lead in supporting and encouraging the effort through such actions as antitrust reform, tax breaks for capital gains, and tax credits for research and development. It is clear that consortia will play a key role in any future foreign dependence action plan.

E. CONCLUSIONS AND RECOMMENDATIONS

This study resulted in conclusions about the extent and nature of foreign dependence in the specific case study areas as well as from an overall economic perspective. It also resulted in recommendations for actions to mitigate current foreign vulnerabilities. It is clear from this assessment that foreign vulnerability is a continuing problem for the nation and that concerted action by the Government will be required to solve it. The following provides summary conclusions and recommendations, complementing the specific case study recommendations found in Section C.

Foreign Vulnerability is a Critical National Problem. Analyses have shown that foreign vulnerability is not a single, discrete problem that can be easily identified and cured. It encompasses many smaller problems that have incremental (but interrelated) impacts on our national security. It is difficult to prove that each dependence creates an intolerable level of vulnerability on its own, but there is no doubt that the total foreign dependence problem is extremely threatening to the nation. Within the case study areas, for example, there has been a massive loss of market share over the past decade. In the last 10 years, the U.S. share of the world market for automatic test equipment has dropped from 90 percent to 50 percent, while Japan's has increased from less than 10 percent to about 50 percent. The foreign share of the U.S. machining center market grew 45 percent over a six year period, and remains at 57 percent today. Domestic controller manufacturers now represent only 8 percent of the world market, in contrast to the 49 percent share of the world market that is now held by the Japanese. In these three cases, a domestic industry still exists but it is severely weakened, unable to perform the R&D required to remain viable or to take other significant actions to reverse the trends. This situation is repeated time and time again across many of our most critical national industries, creating a problem that not only warrants but demands the attention of the Government. It is essential for the Government to recognize that the

relative absence of individual "show-stoppers" does not diminish the seriousness or urgency of the foreign dependence issue.

Processes and Technologies are a Growing Area of Foreign Dependence Risk. To date, most foreign dependence analyses have examined current defense products that can only be obtained from offshore. These studies have shown that foreign dependencies are extensive and pervasive, extending through the lower tiers of the industrial base. However, our dependence on foreign sources for advanced process and product technologies must also be taken into account when assessing the threat to the nation posed by foreign dependence. With the off-shore shift of both the technology base and production base, today's advanced technologies are rapidly becoming tomorrow's foreign dependencies. As has already been proven, we are subject in these areas to both technology denial and technology delay. If we do not take action until we are endangered, we will have waited too long and the technology may be lost. Consequently, it is necessary to take a broad view of foreign dependence, with an eye toward both current and future needs.

Foreign Vulnerability Risk Can be Measured. An important objective of this study was to identify a simple measure that could be used to assess the degree of dependence in a variety of areas and to form the basis for establishing foreign dependence priorities. The HHI Index, which was selected and adapted by TASC for this purpose, provides such a measure. It is conceptually well suited to the problem, it can be easily applied, and it has the additional benefit of wide acceptance among the economic community. However, additional research is required to establish meaningful threshold levels and to test results over a wider variety of potential vulnerabilities.

Foreign Dependencies Require Both Generic and Tailored Solutions. Many of the causes of foreign dependence are macroeconomic or institutional in nature, and solutions must be implemented through broad national policies that address such factors as the nation's business climate and competitive environment. These are national level problems that cannot be solved by DoD or industry alone. At the same time, each industry is different and requires an individual approach to resolving specific vulnerability issues. For example, the U.S. has a strong lead in some types of customized machine tools; but success in other markets will be required for the industry to generate revenue for R&D and build the broad capabilities necessary for long-term success. In other industries, an effective approach to dependence resolution would involve a set of industries that share a common objective. For example, it would be fruitless to build a world class capability for GaAs chips without also building a domestic capability to manufacture and test these chips. Most importantly, industry must play a strong role in the develop-

ment of these solutions to ensure that they reflect an in-depth understanding of industry dynamics, build strongly on market opportunities and commercial trends, and are consistent with industry's own strategic plans.

Industrial Strategies are Essential to Foreign Dependence Resolution. The policy options described in Section D include only a few of the many actions that could be taken by the Government to reduce our foreign vulnerability for key defense items. These actions can be taken separately—as part of an *ad hoc* program—or they can be taken as part of an overall strategy designed to improve competitiveness in key areas. There has been an unwillingness to pursue such strategies, since the Government is wary of giving "preferred treatment" to a few selected industries. Manufacturing and industrial base issues are treated as puzzle pieces, and unfortunately, no agency is responsible for putting the puzzle together. This treatment will not be effective when other nation's of the world—from Japan, to European allies, to the Soviet Union—have made industrial base development an important national priority.

A Government Focal Point is Required for Industrial Strategies. For a number of years, a primary impediment to effective industrial base strategies has been that no single organization within the Government has the mission and responsibility to develop and carry them out. Even the tools that are available to support industrial policies and programs are fragmented, lodged within different Service and other DoD organizations, and applied sporadically. As a result, this study and prior foreign dependence assessments have shown that the nation is facing a major and growing problem—and that the Government has made few if any effective efforts to solve it. The need for centralized management of industrial issues is reinforced by recent actions of Congress, which have required DoD to perform unprecedented analyses of industrial base problems, priorities, and actions.

CHAPTER IV
EFFECTIVENESS OF PAST ATTEMPTS TO EXPLOIT DEPENDENCE ON FOREIGN TECHNOLOGY

A. INTRODUCTION

Dependence on foreign sources to supply key high-technology components of weapon systems can lead to U.S. vulnerability if potential conflicts of supplier nations' interests with those of the U.S. make continuity of supply uncertain in times of crisis. Previous sections of this report note that this type of vulnerability, corresponding to surge and mobilization vulnerabilities in the classification presented earlier, depends on intentional actions by suppliers. Many factors, varying widely from situation to situation, would determine how the supplier might choose to act, what options the U.S. might be able to exercise in response, and what the net effect of attempts to exploit these U.S. vulnerabilities could be.

Until recently, domestic U.S. suppliers were at or near the cutting edge of essentially all technologies necessary to design and build the qualitatively superior weapon systems we have needed to implement the strategy of using a relatively small force of defenders with highly capable military equipment to deter a numerically superior enemy. In many areas, we were sole suppliers of state-of-the-art components and systems.

Because we have only recently been dependent on other nations for high-technology weaponry, recent history provides few direct lessons about the past effects and effectiveness of attempts by other nations to impede the flow of high-technology items to manufacturers of U.S. weapon systems.[1] The chapter that follows attempts to bridge this gap by examining mirror-image cases in which the U.S. or its allies tried to use denial of exports of high technology components, materials, or know-how to impede foreign programs to develop or manufacture advanced military systems.[2] These cases provide the most relevant evidence available to help predict:

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1 Examples of real or anticipated attempts to exploit U.S. vulnerability to interruption of supplies of strategic materials, such as oil or strategic metals, are much more common. So are pre-World War II examples of denial to the U.S. of state-of-the-art weapon imports or technology imports needed to produce state-of-the-art weapon systems domestically.

2 In one of the cases, such an action was directed against the U.S. (by Canada).

- under what circumstances high technology supplier nations will attempt to convert dependencies into vulnerabilities by withholding or threatening to withhold exports, and

- under what circumstances these attempts will succeed (and to what extent and in what sense they will succeed).

B. METHOD

SAIC gathered information for case studies from published literature,[3,4,5] consultations with senior academic and industrial specialists, and interviews with present and past U.S. policymakers. Table IV.1 lists some of the individuals consulted in the course of this study. The initial cases focused on U.S. attempts to thwart or impede foreign efforts to develop and build high-technology systems (particularly weapons) by restricting exports to the country of concern of U.S. and allied high-technology know-how, components, and materials.

The criteria used to select cases reflect circumstances analogous to possible future U.S. vulnerabilities arising from dependence on foreign high technology. In all of the cases, denial or threat of denial of a high-technology export was a primary element of the supplier's strategy for influencing the recipient. In most of the cases, the recipient was highly dependent on the supplier for the item in question, having little or no present, near-term, or even mid-term ability to produce the item indigenously. In many of the cases, the supplier's primary objective in denying the export was to impair the present or future military capability of the recipient, either generally or in some specific respect. Some of the most interesting cases involve attempts by the supplier to thwart the recipient's efforts to reduce vulnerability by developing an indigenous manufacturing or technology base.

The best-known examples of the use of denial of high-technology exports to influence policy or restrict development of military capability include U.S. and allied denials of nuclear fuel cycle exports to countries suspected of undertaking clandestine programs to develop nuclear weapons (Pakistan being the best example);

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3 The most useful and comprehensive sources were references 4 and 5.

4 Hufbauer, G. C., J. J. Schott, and K. A. Elliott, *Economic Sanctions Reconsidered: History and Current Policy* (Washington, DC: Institute for International Economics, 1985).

5 Galdi, T. W, and R. D. Shuey, *U.S. Economic Sanctions Imposed Against Specific Foreign Countries 1979 to the Present*, Report 88-612 (Washington, DC: Congressional Research Service, 1988).

and U.S. denials of export licenses to Iran for bought-and-paid-for aircraft and aircraft parts.

Information gathered in an initial round of study and discussions was presented to U.S. experts who are knowledgeable about the technologies in question, about U.S. attempts to impede foreign development and production efforts by control of exports of high-technology products and materials, or both. Members of this group suggested additional cases for consideration and offered their expert assessments of the success of denial of high-technology exports in impeding the foreign development or production efforts.

TABLE IV.1
SENIOR CONSULTANTS

John M. Deutch	Provost, Massachusetts Institute of Technology (Ex-Undersecretary of Energy)
Edward A. Frieman	Director, Scripps Institute of Oceanography (Ex-Director of Energy Research)
Eugene G. Fubini	Private consultant (Ex-Chairman, Defense Science Board)
Donald A. Hicks	President, Hicks and Associates (Ex-Deputy Undersecretary of Defense, Research & Engineering)
Gary Hufbauer	Professor of International Economic Policy, Georgetown University
Bobby R. Inman	Chairman and CEO, Westmark Corp. (Adm, USN (ret.); Ex-President, MCC; Ex-Director, NSA; Ex-Deputy Director, CIA)
Clinton W. Kelley, III	Science Applications International Corp. (Ex-Special Assistant to the Director/DARPA for Strategic Computing)
Julian C. Nall	Institute for Defense Analysis (Ex-National Intelligence Officer for Science & Technology)
Victor H. Reis	Lincoln Laboratories, Massachusetts Institute of Technology (Ex-Dep. Director, White House Office of Science & Technology Policy)
Matthew W. Tobriner	Science Applications International Corp. (Ex-Director, Plans & Development, OUSDRE)

C. INSTRUCTIVE CASES

Table IV.2 briefly summarizes a subset of the cases, chosen to illustrate insights gained into the efficacy of denial of high technology exports. Examination of the suppliers' behaviors in this set of cases (and of the consequences of those behaviors for the recipients) illustrates many of the factors that should be considered in developing an appropriate level of concern for postulated U.S. vulnerabilities arising from dependence on foreign suppliers for high-technology components of weapon systems.

The examples are in principle also relevant to the categories of vulnerability—more central to this report—which arise from deficiencies in the manufacturing base or the technology base of the recipient country. However, most of the cases involve recipient countries unlike the U.S., with little or no realistic prospect of independent action (using indigenous general manufacturing capability or know-how) to reduce their vulnerability in the near- or mid-term, or to correct the injury quickly once the vulnerability has been exploited, without the help of an alternate supplier. As noted earlier, the supplier's objective in many of the cases is precisely to use present dependence on foreign high technology to prevent the recipient country from developing indigenous military manufacturing capabilities, which are thought to constitute a threat to the country's neighbors.

The analogy of these cases to future U.S. circumstances is thus imperfect, particularly in the cases involving third-world countries with very limited local resources to invest in remedying their vulnerabilities. These differences place important limitations on conclusions that might be drawn directly from the cases, but explicit attention to the differences noted above (as in the analysis that follows the case summaries below) should preserve as much as is possible of the validity of the lessons learned.

The remainder of this section presents brief summaries of the selected cases. Each summary begins with tabular information that identifies the parties to the case, the exports that the suppliers denied or delayed in an attempt to influence the recipient, and results the suppliers hoped to achieve. A short narrative description of the case and its outcome follows immediately afterward The cases are presented in alphabetical order, by recipient country.

Table IV.2

HIGH-TECHNOLOGY EXPORT CONTROL CASES

Recipient	Lead Supplier	Third Parties	Item or Technology	Objective of Denial	Dates	Incident	Outcome	Comments
Argentina	U. S.	Switzerland W. Germany USSR	Enriched U; heavy water; control computer	Non-proliferation (accept safeguards	'78-'82	Applic. for licenses for res. reactor fuel, power reactor D_2O, D_2O plant computer	Exports denied under Carter; Reagan approves	Indigenous abilities delayed, then strengthened
Brazil	U. S.	W. Germany France (URENCO)	Enriched U; enrichment tech.	Derail purchase of full nuclear fuel cycle	'78-'81	Order for enrichment, fuel fab., reactors, reprocess. from W. Germany	European U bought w/ US OK; FRG deal modified	Indigenous abilities delayed; strong safeguards applied
China	U.S.	None	High-tech. trade and tech. xfer	End sale of missiles	'87-'88	Missiles sold to Iran menaced Persian Gulf shipping	Satisfactory assurance that no sales taking place	Threat succeeded; sales were worth less than high-tech. trade
India	U. S. Canada	France W. Germany USSR Sweden	Enriched U; reactor help; hot isostatic presses	Disapprove '74 "PNE;" no future support for nucl. expls.	'75-'78	Indians detonated "peaceful nucl. device;" U.S., Canada halted cooperation; others stop nuclear-related sales.	Indians finished alone European fuel bought w/ US OK	Power program disrupted; ultimately more in-country
Iran	U. S.	None	Aircraft parts; dual-use chemicals	Apply pressure re: hostages; stop chemical war	'79-'88	Iran took U.S. diplomats hostage; used gas in war with Iraq	Hostages released on Iranian schedule; gas war continued	Iranian AF still crippled; others supplied embargoed chemicals
Iraq	U. S.	Italy	Gas turbines; dual-use chemicals	Deny war eqpt.; stop chemical war	'80-88	U.S. wanted to limit sales to Iran-Iraq combat.; both sides used gas	War, including chemical warfare, continued	Others supplied equipment, embargoed chemicals

Table IV.2

HIGH-TECHNOLOGY EXPORT CONTROL CASES (continued)

Recipient	Lead Supplier	Third Parties	Item or Technology	Objective of Denial	Dates	Incident	Outcome	Comments
Pakistan	U. S. Canada France	Netherlands UK, FRG, China Switzerland	Reactor fuel; fuel fab. equip.	Delay/prevent nucl. weapon development	'70s -'90s	Since Indian "PNE," Pakistan has tried to buy or develop technol. for nuclear weapons	Led by U.S., many nations have blocked export of equip.; prog. delayed many years.	Clandestine purchases hard to block; native development has been slow and hard
S. Africa	U. S. Canada	W. Germany France Israel(?) Sweden	Enriched U reactor fuel	Prevent nuclear testing	'75-'82	Using locally refined technol., S. Africa showed most nucl. weapon capabilities	Apparent preps. for a nucl. test were abandoned	Indigenous develop. of capability hard to block in developed country
S. Korea (Repub. of Korea)	U. S. Canada	France	Enriched U fuel; power reactors	Derail purchase of reprocessing	'75-'76	S. Korea tried to buy a reprocessing plant from France	S. Korea abandoned plans for reproc. plant	Defense, power prog. were more important than weapon option.
Taiwan (Repub. of China)	U. S.	None	Reactor fuel; power reactors	Halt reprocessing	'76-'77	U.S. got reports of clandestine reprocessing	Taiwan renounced nucl. weapon option; bad reports ceased	Vulnerable nation succumbed to pressure
USSR	U. S. COCOM	Various	High tech., esp. comput'rs, electronics	Prevent use in design/mfgr. of weapons	'45-'89	Ongoing attempt to deny Soviets high tech. prods. & info.	Tech. transfer severely limited & delayed	Sanctions have been imperfect, but very successful
USSR	U. S.	UK	Gas pipeline components	Delay/discour. USSR-Europe gas pipeline	'82	U.S. delayed/tried to deny British firm a reexport lisence.	License was appr'd; components were supplied	Denial earlier ('79?) might have helped U.S. cause more

Recipient:	Argentina[6]
Supplier:	United States
Third Parties:	Switzerland, West Germany, USSR
Items or Technologies:	Enriched uranium reactor fuel; heavy water; natural uranium-fueled reactors; heavy water production.
Objectives of Denial:	Block acquisition of facilities and materials that could support production of nuclear weapons; encourage Argentine political commitment to non-proliferation.

Argentina has Latin America's most advanced nuclear research and development capabilities. It has refused to sign the 1968 Nuclear Non-Proliferation Treaty and the Treaty of Tlatelolco (prohibiting nuclear weapons in South and Central America). Its research reactors are powered by U.S.-supplied high- and medium-enrichment uranium. Its power reactors use natural uranium[7] fuel and require heavy water as a moderator.

The Carter and Reagan administrations withheld approval for resupply of enriched uranium for Argentina's research reactors. The Carter administration withheld approval of resale by West Germany of U.S.-produced heavy water for Argentina's second power reactor, which was being built by a German contractor; the Reagan administration later approved this resale as part of its campaign to re-establish the U.S. as a "reliable nuclear supplier." The Reagan administration also approved export of a U.S.-supplied process control computer for use in a heavy water production plant built for the Argentines by the Swiss. (The Carter administration tried to discourage this sale.)

The Soviet Union has provided some enriched uranium fuel for Argentina's research reactors. Argentina claims to have developed an indigenous uranium enrichment plant (thought to be a laboratory- or pilot-scale facility). Indigenous uranium deposits and the Swiss heavy-water plant insulate Argentina's power reactors from foreign dependence. Argentina's nuclear options remain open and under her control.

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6 Hufbauer, Schott, and Elliott, *op. cit.*, pp. 592-597; Galdi and Shuey, *op. cit.*, pp. 17-18.

7 Argentina has plentiful indigenous uranium reserves.

Recipient:	Brazil[8]
Supplier:	United States
Third Parties:	West Germany, France (URENCO)
Items or Technologies:	Enriched uranium reactor fuel; uranium enrichment technology.
Objectives of Denial:	Block acquisition of facilities that could support production of nuclear weapons.

Brazil has two U.S.-built power reactors. The 1971 contract for those reactors called for fueling by uranium mined in Brazil and enriched in the U.S. Brazil has ratified, with reservations, the 1967 Treaty of Tlatelolco (prohibiting nuclear weapons in South and Central America) but has refused to sign the 1968 Nuclear Non-Proliferation Treaty. A 1975 Brazilian contract with West Germany calling for construction of up to eight power reactors included proliferation-sensitive facilities and technology for uranium enrichment, fuel fabrication, and reprocessing of spent fuel (with recovery of plutonium). Operation of these facilities would have been subject to unusually stringent international safeguards, but Brazil has refused to commit itself to inspection of all of its nuclear facilities (full-scope safeguards), a requirement for U.S. nuclear cooperation since 1978.

After approving an initial shipment of enriched uranium fuel to power the Brazilian reactors and offering to provide U.S. services if Brazil abandoned its plans to acquire enrichment and reprocessing facilities, the Carter administration did not act on Brazilian requests for approval of additional fuel shipments. The Reagan administration released Brazil from its contractual commitments to purchase U.S. enrichment services for its U.S. reactors, allowing Brazil to buy these services from URENCO (the European enrichment consortium) without penalty. Severe technical and economic difficulties have delayed construction of the German reactor and fuel cycle facilities, possibly indefinitely.

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8 Hufbauer, Schott, and Elliott, *op. cit.*, pp. 587-590; Galdi and Shuey, *op. cit.*, pp. 29-30.

Recipient:	China[9]
Supplier:	United States
Third Parties:	None
Items or Technologies:	Broad range of high-technology items, some dual-use.
Objectives of Denial:	End Chinese sales of Silkworm surface-to-surface missiles to Iran.

To protest Chinese sale to Iran of missiles likely to be directed against U.S. and allied shipping in the Persian Gulf, the Reagan administration announced suspension of an ongoing liberalization of export restrictions on sale to China of high-technology goods and services. The suspension was lifted about 4 months later when the U.S. received satisfactory assurances that Silkworms were then not being sold to Iran.

Recipient:	India[10]
Suppliers:	United States, Canada
Third Parties:	France (URENCO), West Germany, USSR, Sweden
Items or Technologies:	Enriched uranium fuel, hot isostatic presses.
Objectives of Denial:	Express disapproval of 1974 "peaceful nuclear explosion;" prevent future use of supplied materials and facilities in nuclear explosive devices.

After India's detonation of a nuclear explosive device in 1974, Canada canceled all plans for further nuclear cooperation and suspended shipment of fuel, equipment, and spare parts for Indian reactors built by Canada. (Material for the Indian device is thought to have been produced in a Canadian-supplied reactor.) The embargo delayed by several years completion (by the Indians) of a power reactor that the Canadians had been building. The Soviet Union has supplied heavy water to maintain operation of a Canadian-built power reactor and has

9 Galdi and Shuey, *op. cit.*, pp. 52-54.

10 Hufbauer, Schott, and Elliott, *op. cit.*, pp. 496-500, 598-602.

offered to build additional power reactors for India. India still refuses to meet Canadian demands to upgrade safeguards on Canadian-supplied reactors.

A reprocessing plant built without foreign assistance (and therefore not subject to international safeguards) was placed by the Indians at a power generating complex containing a reactor fueled by U.S.-supplied enriched uranium. The U.S. Nuclear Non-Proliferation Act of 1978 prohibited nuclear exports after 1980 to nations maintaining such unsafeguarded civil nuclear facilities. Three shipments of fuel were approved for the Indian reactor in 1978-1980 after considerable controversy; a September 1980 request was not approved. The U.S. and India eventually compromised, agreeing to continue safeguards on U.S.-supplied facilities and materials at the power station, with new fuel supplies to come from URENCO, the European enrichment consortium. After arrival of the French fuel, operation of the power station still had to be severely curtailed due to shortages of safety-related spare parts still embargoed by the U.S.; eventually, a West German supplier for these parts was found.

Recipient:	Iran[11]
Supplier:	United States
Third Parties:	None
Items or Technologies:	Spare parts for U.S.-supplied military equipment; dual-use chemicals.
Objectives of Denial:	Pressure Iran to release U.S. hostages; maintain neutrality in Iran-Iraq war; impede production of chemical weapons for Iran-Iraq war.

The U.S. suspended all shipment of military spare parts to Iran after Iran seized 54 U.S. diplomats as hostages in 1979. Because Iran had obtained nearly all its military equipment from the U.S. prior to the downfall of the Shah, this soon impaired Iranian military capability severely. In particular, most of the Iranian Air Force was grounded as first some planes were cannibalized to provide parts for others and then certain parts became completely unavailable. Because many aircraft parts are one-of-a-kind items, work-arounds for such a denial are particularly difficult. At the end of the 1980s, these planes were still of very little use to Iran.

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11 Hufbauer, Schott, and Elliott, *op. cit.*, p. 487; Galdi and Shuey, *op. cit.*, pp. 97, 100, 103, 107.

When the Iran-Iraq war broke out in 1980, the U.S. declared itself officially neutral, which made export of military items to either combatant illegal. It also prohibited approval of transfer of U.S. equipment to the combatants by third parties.

Reports of use of chemical weapons by both sides in the Iran-Iraq war led the U.S. to embargo shipment of precursor chemicals (which are also agricultural pesticide precursors) to the combatants. Since reports of use of these weapons by Iran continued, other sources must have been found, presumably after some delay and at higher prices.

Recipient:	Iraq[12]
Supplier:	United States
Third Parties:	Italy
Items or Technologies:	Gas turbines; dual-use chemicals.
Objectives of Denial:	Maintain neutrality in Iran-Iraq war; impede production of chemical weapons for Iran-Iraq war.

As noted above, when the Iran-Iraq war broke out in 1980, the U.S. declared itself officially neutral, which made export of military items to either combatant illegal. It also prohibited approval of transfer of U.S. equipment to the combatants by third parties.

The U.S. denied an export license that would have allowed General Electric to sell gas turbine engine cores to an Italian shipbuilding company for installation in Iraqi frigates.

As was the case for Iran, reports of use of chemical weapons by both sides in the Iran-Iraq war led the U.S. to embargo shipment of precursor chemicals (which are also agricultural pesticide precursors) to the combatants. Since reports of use of these weapons by Iraq continued, other sources must have been found, presumably after some delay and at higher prices.

12 Galdi and Shuey, *op. cit.*, pp. 100, 105-107.

Recipient: Pakistan[13]

Suppliers: United States, Canada, France

Third Parties: Holland, UK, W. Germany, Switzerland, China,

Items or Technologies: Uranium reactor fuel; reactor spare parts; nuclear fuel fabrication facility; high-speed motor control units; large hot isostatic presses; flash X ray unit.

Objectives of Denial: Block acquisition of facilities and materials that could support production of nuclear weapons; upgrade safeguards on existing nuclear facilities.

When India detonated its "peaceful nuclear explosive" in May of 1974, Pakistan had one operating nuclear power station, consisting of a natural uranium-fueled heavy water-moderated reactor built and operated with extensive Canadian assistance; a Canadian-supplied fuel fabrication facility was on order. When Pakistan refused to pledge not to build its own PNE, Canada suspended shipment of spare parts for the reactor and deferred shipment of the fuel fabrication plant. During several years of negotiation, Pakistan rejected all Canadian offers of renewed supply and cooperation in exchange for non-proliferation assurances. Without Canadian parts and technical assistance, operation of the power station rapidly deteriorated.[14]

In early 1986, Pakistan ordered a reprocessing plant from France. When covert Pakistani efforts to buy components for a centrifuge-based uranium enrichment plant (plans for which had been stolen from URENCO) were discovered by the Europeans, France modified its offer of assistance under U.S. pressure. It urged Pakistan to accept a coprocessing plant (which produces mixed uranium-plutonium for recycling into reactor fuel, not separated plutonium) instead of the promised full reprocessing plant. Pakistan did not accept the modified offer and eventually declared the contract void.

13 Hufbauer, Schott, and Elliott, *op. cit.*, pp. 501-504, 636-643; Galdi and Shuey, *op. cit.*, pp. 149-153.

14 After the cut-off of Canadian assistance, the plant produced at 26% of capacity in 1976-1977 and at 5.5 percent of capacity in 1979-1980.

Since discovery of the Pakistani plans to build a clandestine uranium enrichment plant, the U.S. has led and coordinated efforts to discourage potential suppliers of components for the Pakistani nuclear weapon development program. Items denied include motor controllers suitable for enrichment centrifuges, hot isostatic presses, and a flash X ray unit. Without these denials by supplier nations, there is little doubt that the Pakistanis would have had much more success much sooner. In delaying the Pakistani program by many years, these sanctions have been a success.

Chinese technical cooperation with the Pakistani nuclear weapon design program has been reported. Such cooperation could be useful in avoiding mistakes in design. It would also reduce the need for actual tests of candidate designs (which could have high political costs for a state presently outside the nuclear weapon "club"), allowing stockpiling of an untested design with some confidence that it would function if employed.

Recipient:	South Africa[15]
Supplier:	United States, Canada
Third Parties:	West Germany, France, Israel(?), Sweden
Items or Technologies:	Enriched uranium reactor fuel; hot isostatic presses; supercomputer; reactor management services.
Objectives of Denial:	Block acquisition of facilities and materials that could support production of nuclear weapons; discourage production and testing of nuclear weapons.

South Africa has the most advanced nuclear research and development program in Africa (with the possible exception of Israel's). It has a U.S.-supplied research reactor powered by U.S.-supplied high-enrichment uranium fuel. With some early West German assistance, it has developed an unusual process for enrichment of uranium, details of which have not been revealed publicly. It has plentiful indigenous uranium reserves.

When the U.S. was reluctant to supply two South African power reactors and their fuel, South Africa made these purchases from France.

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15 Hufbauer, Schott, and Elliott, *op. cit.*, pp. 523-529; Galdi and Shuey, *op. cit.*, pp. 182-186.

According to press reports, in 1977 a Soviet surveillance satellite detected apparent preparations in South Africa for an underground nuclear test and U.S. reconnaissance confirmed the Soviet reconnaissance. Several Western governments threatened severe repercussions if such a test were carried out, and it was not. In late 1979, a U.S. satellite designed to detect nuclear explosions reported a suspicious event in the southern Indian Ocean. Some analysts believe this was a South African (or Israeli or joint South African-Israeli) nuclear test. There have been no new public reports of suspicious events in that part of the world since then.

The Reagan administration increased nuclear cooperation with South Africa, with the avowed intention of maintaining some influence in nuclear matters. Exports approved included hot isostatic presses of limited size, a supercomputer sold to a defense contractor with powerful modeling capability that could be applied to nuclear weapon design, and a long-term contract for technical management services to assist in operating the French-supplied power reactors.

Recipient:	South Korea[16]
Suppliers:	United States, Canada
Third Parties:	France
Items or Technologies:	Nuclear power reactors; reprocessing plant.
Objectives of Denial:	Discourage acquisition of facilities and materials that could support production of nuclear weapons.

In early 1975, South Korea presented a good non-proliferation profile to the world. It completed its ratification of the nuclear Non-Proliferation Treaty and negotiated credit arrangements with Canada for purchase of a large natural-uranium-fueled, heavy-water-moderated power reactor. South Korea also had enriched-uranium-fueled, light-water-moderated power reactors on order from the U.S., to be financed by low-interest Export-Import Bank loans. When ongoing negotiations with the French for possible purchase of a reprocessing plant[17] were publicly announced at mid-year, the U.S. and Canada threatened not to build the desired power reactors and tightened the originally proposed terms for their reactor sales to

16 Hufbauer, Schott, and Elliott, *op. cit.*, pp. 505-507.

17 Such a plant made no economic sense in a civilian power program the size of South Korea's, but would have made available the option of recovering plutonium for nuclear weapons from uranium fuel irradiated in the power reactors.

the South Koreans. (Presumably, the U.S. also brought other forms of pressure to bear.) By the beginning of the new year, South Korea had decided to abandon its plans to purchase a reprocessing plant.

Recipient:	Soviet Union[18]
Suppliers:	United States, COCOM[19]
Third Parties:	Numerous
Items or Technologies:	Broad set of cutting-edge technologies with military applications, particularly electronics and computers.
Objectives of Denial:	Avoid expansion of technology base supporting development of Soviet weapon systems, to maintain qualitative advantage of U.S./NATO weapon systems.

Since the end of World War II, the U.S. and its allies have maintained controls, which differ from country to country, on exports that would increase the military capabilities of the Soviet Union and its allies. Neutral industrial countries have often implicitly supported these policies. The controls have a complex history.[20] They have always forbidden sales of munitions and nuclear energy items. Controls on other items have varied over time, with a trend since the 1960s toward sharper focus on items of clear strategic importance. After some general relaxation during the *detente* of the 1970s, emphasis in the 1980s shifted to control of transfer of high-technology items and know-how.[21]

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18 Hufbauer, Schott, and Elliott, *op. cit.*, pp. 211-220.

19 COCOM (Consultative Committee on Multilateral Export Controls) is an "unofficial" working group maintained by the NATO countries (minus Iceland and Spain) and Japan to implement an embargo on "strategic" exports to the Soviet Union and its allies. Since its establishment in 1949, it has operated by unanimous consensus to maintain (and consider exceptions to) an agreed lowest-common-denominator list of controlled items.

20 Office of Technology Assessment, *Technology and East-West Trade* (Washington, DC: U.S. Congress, 1979) and *Technology and East-West Trade: An Update* (Washington, DC: U.S. Congress, 1983).

21 U.S. Central Intelligence Agency, *Soviet Acquisition of Western Technology* (Washington, DC: U.S. Central Intelligence Agency, 1982).

Export controls have attempted to limit Western contribution to improvement of the quality[22] of Soviet military equipment. During the 1970s, the Soviet Union was able to obtain—legally and illegally—some Western technology that helped it narrow the qualitative gap, but by and large controls intended to limit transfer of militarily useful high technology, including know-how with "dual" (civilian and military) applications, have succeeded. Had they not succeeded, Soviet weapon systems could be made stronger, lighter, and smarter by incorporating materials and components that are readily available for domestic use in the West. They could be made cheaper and more reliable by utilizing Western manufacturing equipment in their production. Powerful imported computers would be available to support Soviet design activities, including those of the military industry, and powerful electronic components would be available to help implement the designs.

Recipient:	Soviet Union[23]
Supplier:	United States
Third Parties:	United Kingdom
Items or Technologies:	Natural gas pipeline equipment
Objectives of Denial:	Block construction of a pipeline to bring Soviet natural gas to West European markets

In 1981-1982, components were being manufactured in Western Europe for a pipeline to carry natural gas from Soviet oil wells to West European customers. Following a Soviet-inspired declaration of martial law in Poland, the U.S. extended an existing embargo on export to the Soviet Union of oil and gas exploration equipment[24] to cover oil and gas transmission equipment as well. The U.S. then attempted to deny a required export permit to a British company that was building pipeline fittings using U.S. technology under license. There had been no embargo in place when the U.S. owner of the technology had agreed to this use of the license in 1979. After highly public discussions in which the U.S. highlighted the political dangers of the pipeline and the West Europeans indicated their determination to proceed, the embargo was lifted and the components were shipped.

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22 The Soviet Union and its allies have long been able to produce weapons they have developed in very adequate numbers.

23 Galdi and Shuey, *op. cit.*, pp. 213-215, 218, 221

24 Implemented as part of a broader response to the Soviet invasion of Afghanistan in 1979.

Recipient: Taiwan (Republic of China)[25]

Supplier: United States

Third Parties: Canada

Items or Technologies: Nuclear power reactor; enriched uranium reactor fuel

Objectives of Denial: Discourage acquisition of facilities and materials that could support production of nuclear weapons

By late 1975, reports had reached the U.S. government that Taiwan was secretly reprocessing irradiated reactor fuel on a larger-than-laboratory scale. The fuel was thought to have come from a Taiwanese reactor supplied by Canada (which was not strictly safeguarded after Canada broke diplomatic relations with Taiwan in 1970) or from abroad. After several months of private warnings, the U.S.—which for world political reasons was the only supplier willing to provide reactors and enriched uranium fuel for Taiwan's power program—delayed (indefinitely) approval of export to Taiwan of two power reactors and a shipment of low-enrichment uranium fuel for a research reactor. Eight months later, the U.S. revealed its concerns publicly. Taiwan responded by denying ever having operated any reprocessing facility larger than a hot cell at its nuclear research center and pledging that it had no intention of developing nuclear explosives or engaging in reprocessing. About a year later, it dismantled the hot cell and shut down the research reactor (for a period eventually lasting 18 months) at its Institute for Nuclear Energy Research. When it was satisfied that Taiwan was not engaging in clandestine reprocessing, the U.S. resumed licensing of nuclear power and research exports to Taiwan.

D. ANALYSIS

Many of the cases summarized above nominally end with the recipient country getting most or all of what it sought when the supplier denied (or threatened to deny) it a high-technology export. Nonetheless, in most cases the denial was costly to the recipient in time and money, and the recipient had to modify its goals, its means of reaching its goals, or its schedule as a result of the denial. Unless circumstances other than the recipient's dependence for a high-technology import (for example, South Korea's and Taiwan's military dependence on the U.S.) gave the supplier overwhelming leverage over the recipient, usually the recipient eventually

[25] Hufbauer, Schott, and Elliott, *op. cit.*, pp. 540-543.

found a way to work around the denial to reach goals that were fundamentally important to it. However, the denial almost always bought the supplier time to try other means to accomplish *its* goals, which may have made the costs of the action worthwhile from the supplier's point of view. Those denials that were most effective for the longest time (for example, U.S. and Allied interference in Pakistan's nuclear weapon development program, and COCOM's largely successful embargo on export of powerful computer technology to the Soviet Union) required high levels of effort, vigilance, and international cooperation, sustained over long periods of time, to achieve success.

The examples above were drawn from a broader history of U.S. and allied attempts to apply economic sanctions to achieve political and military ends, of which they are a relatively small subset. They differ from more typical examples of economic sanctions in several ways. In contrast with "classic" instances of other sanctions, such as broad trade embargoes or suspension of food, development, or military assistance, high-technology export denials almost never produce significant economic impact in the recipient nation (*per capita* or as a fraction of gross domestic product). Whereas other types of sanction are often intended to coerce some behavior (for example, refrain from or reverse some objectionable action), high-technology export denial is usually intended to restrain more generally the recipient's capability to do mischief in the future.

Hufbauer, Schott, and Elliott[26] found that the following factors (a modified list extracted from the authors' "Nine Commandments") were useful retrospective "predictors" of success in attempts to apply general economic sanctions:

- the recipient is destitute, powerless, and highly dependent on the supplier;
- the recipient is inclined to accede by friendship and other important economic and political ties (and other key aspects of the bilateral relationship are strong and important enough to withstand the inevitable backlash from the sanctions);
- costs of the sanctions to the recipient are relatively high;
- the supplier's goals are modest (that is, the political and economic costs of compliance are acceptable to the recipient because his important fundamental interests are not placed at risk);

26 Hufbauer, Schott, and Elliott, *op. cit.*, p. 81-92.

- the supplier is determined, persistent, and willing to pay his costs (that is, his important fundamental interests are at stake);

- costs of the sanctions to the supplier are relatively low;

- alternate suppliers agree (or can be made to agree) to join in, not thwart, the sanctions.

Once they are stated, these predictors of the success of general economic sanctions seem obvious and immutable. The same or similar considerations should apply to the more specialized technology denials that are the subject of this chapter. When we examine (in the mirror that is this chapter's rationale) the consequences of application of these criteria to possible future attempts of other nations to bring pressure to bear on the U.S. through denial of high-technology exports, they tend to brighten (in certain respects) the dark vision of future dependence and vulnerability some authors have painted. The next few paragraphs consider each of the criteria in turn.

Recipient is destitute, powerless, highly dependent on the supplier. The U.S. is rich and powerful. The resources it can bring to bear on problems judged to be of national importance have historically been limited by will, not ability to pay.[27] In high technology, we have a broad and deep base of science and practical know-how. In the past, it has been possible to focus as much of this technology base as is needed on critical national problems. (Often, there has been some delay in reallocation of technical and manufacturing resources, the length of which has depended on the perceived severity of the crisis.)

The U.S. may become highly dependent on foreign sources in areas of high technology where U.S. technical and manufacturing capability have been allowed to erode. The gravity of any resulting vulnerability depends upon the degree to which supply is highly concentrated, in one company (or in a few companies within one country that are forced or allowed to act in concert).

Recipient is inclined to accede. In some cases, the U.S. may be inclined to accede to minor exercises of monopoly power by a company or government in an otherwise friendly country. Tolerance may even be high for small challenges from close allies. However, a visible, deliberate attempt by any country to harm the

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27 The present budget situation, in which deficits and political commitments not to raise taxes seem to constrain our ability to attack important national problems, is a matter of priorities, not ability to pay.

U.S. defense effort (or a U.S. company large enough to attract public attention) is almost certain to produce severe backlash, adversely affecting overall relationships between the U.S. and the supplier country.

Costs to the recipient are relatively high. The U.S. economy is the world's largest, which dilutes the effects of any external factor. Even in smaller economies, technology-based boycotts tend to have negligible effects as a fraction of gross domestic product or on a *per capita* basis.[28] Thus, foreign attempts to deny high-technology exports for use in U.S. weapon systems are unlikely to cause noticeable concrete economic harm. Planners contemplating such attempts would almost certainly know that they could not count on economic effects to help them achieve their policy goals.

Supplier's goals are modest. Modest restrictions, conditions, or demands imposed by the supplier or the supplier's country are relatively easy for most recipients of high-technology exports to accept. However, external perceptions can raise the political costs of compliance for the U.S. defense establishment. Preservation of its status as a superpower is an independent, very important fundamental U.S. interest. Any challenge that places that status at risk is likely to provoke a response disproportionate to the matter immediately at stake.

Supplier is willing to pay his costs, which are relatively low. For reasons stated in the preceding paragraph, the supplier has to be very determined, very persistent, and willing to pay what might become very high costs to consider placing himself in a position of potential confrontation with a superpower. Because almost all potential suppliers of high-technology goods or services have trading relationships with the U.S. that are central to their overall economic well-being, they must consider whether risking general disruption of those relationships is prudent in pursuing otherwise important fundamental political interests.

Alternate suppliers agree not to thwart the sanctions. Many of the same economic and political factors that could make an interruption very costly to an incumbent supplier would make the market to be abandoned a highly attractive target for alternate suppliers. Only a supplier with very tight monopoly control could be confident that the business of an important customer (for the embargoed items and possibly for all products the supplier exports to the U.S.) would not simply be taken by a rival, perhaps permanently. The U.S. would, under most circumstances, be able to at least match any political or economic pressures to join the embargo the incumbent supplier could bring to bear on possible alternate suppliers. In addition, in the mid- to long term, the U.S. could develop domestic supplies or

28 Hufbauer, Schott, and Elliott, *op. cit.*, numerous cases.

substitutes for almost anything it needs badly enough; effectively, an alternate supplier unwilling to participate in a foreign-led embargo is almost always available.

E. CONCLUSIONS

The overall economic, political, and technological strength of the U.S. (and its central importance as a market to other high technology exporters) severely limit the prospects of success of national or corporate strategies based on delay or denial to the U.S. of high-technology components or equipment. In particular, these factors constitute powerful disincentives to explicit actions by foreign companies or countries that might be perceived to restrict or harm U.S. defense capability. Such actions are very unlikely to bring rewards worth their costs, and those in a position to attempt them know this.

The difficulties (and, in many cases, failures) other countries have experienced when they were dependent on others not only for components but also for manufacturing and technical know-how should warn the U.S. of the dangers and possible costs of losing the ability to make things of national importance. Because it is symptomatic of an erosion of the U.S. manufacturing and technology base, the increasing U.S. reliance on foreign manufacturing equipment documented elsewhere in this study poses much more danger of vulnerability to foreign pressure or malevolent action (overtly political or "merely" commercial) than simple foreign dependence for high technology components.

CHAPTER V
CONCLUSIONS

When the study team examined the contents of present U.S. weapon systems, it encountered fewer examples of foreign dependence and vulnerability for key components or of dramatic recent growth in foreign sourcing of components than anticipated. The majority of individual components/devices in the systems studied were domestically produced, or available from several foreign sources in more than one country.[1]

In retrospect, these findings should not have been surprising. Most U.S. weapon systems take from 10 to 15 years to go from conceptual design to full scale production. Fielded technology is based on the state of the art of a previous generation, when foreign inroads into the U.S. market for high technology were less extensive than they are now. In addition, foreign producers of advanced products for the commercial market (like their American counterparts) have shown little interest in recent years in establishing special production facilities to meet Mil Spec requirements. System developers are forced to buy in predominantly domestic niche markets, created to satisfy Department of Defense requirements for old, nonstandard parts.

The finding that there are few cases of vulnerability arising from use of foreign high technology components in U.S. weapon systems should not inspire complacency. The weapon system study's finding of growing foreign dependence in manufacturing technology, and the quantitative analysis of trends in several key manufacturing technologies presented in Chapter III provide additional evidence of the erosion of the U.S. defense manufacturing base that has been noted with alarm by many others.

Vulnerabilities in manufacturing that are developing now (because enabling technologies for manufacturing are migrating offshore along with U.S. market share for the product being made) are an early warning of foreign vulnerabilities that are likely to develop in other areas of the technology base that depend for their support on competitive U.S. industries.

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1 Exceptions included optical filters and filter glass (used in the F/A-18 heads-up display and in the multipurpose display indicators of the F/A-18 and AV-8B aircraft) and molded ferrite yokes (also used in the F/A-18 and the AV-8B). Both come from a single source in Japan.

The prospect of long-term decline of the U.S. base of knowledge and capability in critical technologies like microelectronics, manufacturing equipment, and optics is the most serious vulnerability identified in the course of this study (and by others!). The analysis in Chapter III indicates that dependence on foreign sources for high-technology components, materials, and equipment has already led to serious and growing vulnerability in several key industries. However, the identified supply vulnerabilities (surge and mobilization vulnerabilities in the standard terminology used earlier) can be mitigated at will by stockpiling, substitution, or diversification of supply channels.

Vulnerability arising from dependence on foreign sources for high technology elements of U.S. weapon systems is part of a much larger complex of issues. These are national problems that cannot be solved by DoD alone.

APPENDIX A
EXISTING LEGISLATION AND ITS IMPACT

SURVEY OF LEGISLATION REGARDING FOREIGN DEPENDENCE

This Appendix gives a brief overview of legislation that relates to foreign dependence.[1] The list is not exhaustive, but it touches on a number of relevant issues including foreign purchase of U.S. based firms, access to classified material by foreign owned firms, and establishment of a U.S. source of supply for critical components or materials.

A. DEFENSE PRODUCTION ACT[2]

Title III provides a mechanism for the government to establish a U.S. supply for critical components or materials. Under this authority the President is authorized to expand industrial output and increase supplies to meet DoD requirements. The Title allows for: (1) loans to private business to expand capacity, develop technology, or produce essential materials, and (2) authorizing installation of improvements to factories or other facilities, both government and commercial. Currently, only purchase commitments are being used. DoD decides on which products Title III allocations will be used based on four criteria: (1) criticality of the item; (2) DoD demand is greater than U.S. supply; (3) Title III is the most appropriate way to establish a source; and (4) industry can not do it on their own. In evaluating projects for determining priority, DoD also looks at whether the product is "specable," whether it lends itself to a purchase commitment type contract, whether it can survive commercially after start up, and whether or not it has a Service sponsor. Purchase commitments normally last one to three years. Currently there is no requirement for prime contractors to purchase Title III supported materials, however, there has been an effort to change the FAR to require such purchases in a recent case involving quartz fibers.

Title VII (Section 708) allows the Defense Department to develop voluntary agreements with members of industry and labor for the purpose of aiding the coun-

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1 Much of this material was drawn from "A Survey of Current Government Policy Options for Examining Foreign Dependency Situations which Affect National Security" which is part of a study on Foreign Dependence by the Defense Policy Advisory Committee on Trade. The study is expected to be published shortly.

2 Defense Production Act of 1950, as amended (50 U.S.C., App., Section 2061 *et seq.*).

try's defense. These agreements allow for information sharing and planning the expansion of productive capacity and supply.[3] The Defense Production Act provides for protection from prosecutors under antitrust laws to participants in these voluntary agreements.

Title VII (Section 721) gives the President broad authority to deny foreign acquisition of U.S. based companies if it is determined that the acquisition would negatively affect national security. The determinations are reviewed through the Committee on Foreign Investments in the U.S. (CFIUS) which is chaired by the Treasury Department, but has representation from Defense, State, Commerce, and USTR. There are no formal guidelines or procedures that CFIUS uses although some are being developed and will be issued shortly. The mechanism for reviewing cases being considered includes a mechanism for initiation by acquiring/acquired companies, or by any government agency. Initial screening is performed by interagency letter to determine if a case should be reviewed. Serious concern raised by one major agency is sufficient to initiate an investigation. After a 30-day investigation, the facts are reviewed to determine whether or not the case is forwarded to the President. At least one major agency must find that the acquisition would detrimentally affect national security in order to warrant a Presidential review. All positions are forwarded to the President who makes a final determination within 15 days. Remedies are not clear although the President is given broad authority to deny foreign acquisition and to deny government contracts. Other conditions such as requirement for divestiture before approval, or imposition of management restrictions could arguably be within the President's authority.

B. FOREIGN OWNERSHIP, CONTROL, OR INFLUENCE (FOCI) RESTRICTIONS

FOCI restrictions provide authority to deny access to classified information to a foreign owned or controlled facility. These restrictions can be a major impediment to a foreign entity wishing to buy a U.S. entity which handles significant classified information. However, only the security community within DoD reviews these cases and makes judgements concerning how classified information should be handled. There are several remedies which allow access agreements, and specialty security arrangements which further reduce the ability of FOCI restrictions to deter foreign purchases of U.S. defense entities. No appeal process or review is

3 "The Defense Production Act: A Review and Analysis," Congressional Research Service, March 1, 1982.

required outside the defense intelligence community if a facility is approved for access to classified information under FOCI. Only denials may be appealed.[4]

C. ANTITRUST LEGISLATION

The Justice Department reviews mergers, acquisitions and other business arrangements for antitrust purposes. They do not use national security criteria in making judgments, although there are provisions in the law which allow dominant companies to cooperate on R&D programs which are in the national interest. Since there are no national security exceptions to antitrust considerations, it is possible (and it has happened) that a U.S. buyer is denied the right to acquire a company critical to defense but foreign acquisition of the same company is permitted.[5]

D. TRADE ACT[6]

Section 232 of the Trade Act provides authority for the U.S. government to restrict foreign trade in order to protect an industry which has been determined critical to national security. Cases are managed by the Secretary of Commerce in consultation with the Secretary of Defense. Cases are initiated by an interested party, normally a company or industry associated, but may also be self initiated by the U.S. government. Evaluation criteria include: requirements of defense sectors, need for domestic production, capacity of domestic industry to meet defense needs, impact of foreign competition on the economic welfare of essential domestic industry, and serious effects of imports on unemployment, loss of specialized skills and loss of productive capacity. Remedies vary widely depending on the circumstances of the specific case. A recent ruling on machine tools provided for voluntary restraints by foreign manufacturers and the establishment and funding of a national machine tool development center.[7]

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4 "A Survey of Current Government Policy Options for Examining Foreign Dependency Situations which Affect National Security."

5 "A Survey of Current Government Policy Options for Examining Foreign Dependency Situations which Affect National Security."

6 Trade Expansion Act of 1962, Section 232, as amended (19 U.S.C., Section 1081 *et seq.*).

7 "A Survey of Current Government Policy Options for Examining Foreign Dependency Situations which Affect National Security."

E. BUY AMERICAN ACT[8]

The Federal Buy American Act is one of the major statutes that restricts foreign access to the U.S. government market. It implements policy decisions indicating a preference for goods produced or manufactured in the United States, and requires with some restrictions that in the acquisition of supplies, only domestic end products may be acquired for public use in the United States. In order to qualify as a domestic end product under the regulation, a product must: (1) be manufactured in the United States, and (2) more than half the cost of its components must be from the United States and qualifying countries.[9] Products that do not meet this definition are considered foreign end products. To these offers DoD generally applies a 50 percent evaluation factor to the offered price exclusive of duty when the foreign product is competing against a domestic one. Thus, in a competitive acquisition, if the lowest domestic price is $15, a foreign product would have to be less than $10 to win the competition on a price basis. This is significantly different than civil agencies, which use a 6 percent factor unless the foreign product is competing against a small business or labor surplus concern, in which case a 12 percent factor is used.

The Buy American Act restricts the award of Federal agency contract for procurement of foreign end products from countries considered a signatory "not in good standing" of the Trade Agreements Act of 1979[10] or whose government maintains a significant and persistent practice of discrimination against U.S. products in its government procurement.

F. COMPETITION IN CONTRACTING ACT (CICA) OF 1984[11]

Under the CICA there are two circumstances pertaining to international acquisition or foreign sourcing under which the requirements for full an open competition can be waived: (1) industrial mobilization or experimental, developmental or research work; and (2) contracts required by an international agreement. A third "catch all" exception to the CICA is national security work which can be interpreted in a variety of ways to include foreign dependency. Each of the services and the

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8 41 U.S.C. 10.

9 "Overview of Defense Contracting Statutes and Regulations Affecting International Acquisition," Office Of International Acquisition, Department of Defense, November 25, 1985.

10 19 U.S.C., Section 2501 *et seq.*

11 Title VII, P. L. 98-369.

defense agencies have identified specific mobilization base restrictions. There are currently DoD-wide restrictions on jewel bearings and related items, miniature and instrument ball bearings, precision components for mechanical devices, high purity silicon, high carbon ferrochrome, forging and welded shipboard anchor mooring chain items, and antifriction bearings.[12]

12 "A Survey of Current Government Policy Options for Examining Foreign Dependency Situations which Affect National Security."

APPENDIX B
PRIOR STUDIES

This Appendix consists of summaries of reports that discuss the issue of foreign dependence in the U.S. defense industrial base. The primary category of foreign dependence considered was use of foreign-sourced subassemblies, components, and parts for U.S. military systems. There is also some mention of dependence on foreign-sourced production equipment and machine tools. Other foreign dependence issues (not fully addressed in this Appendix) include offshore manufacturing, economic causes (such as lower cost and higher quality), and government policies.

The studies highlight several varieties of foreign dependence within military weapon systems, including total systems (such as chemical suits); major subsystems (such as heads-up displays and ejection seats); and electronic assemblies and components (including semiconductors and ceramic packages). Other sources of dependence noted in the studies include: electronic test equipment, precision optics, bearings, and chemical and raw materials.

It is evident from these summaries that foreign dependence exists in our military weapon systems. However, the exact impact of foreign sources is hard to measure. DoD has yet to establish a systematic approach to assess this problem. No database or management information system on foreign dependence exists. In order to understand the extent of foreign sourcing, these studies recommend that DoD develop a database comprising all foreign components, parts and technologies that are used in producing U.S. military systems. Data on weapon systems should be collected at the prime contractor, subcontractor and supplier levels to fully grasp the extent of foreign sourcing. This database should be accessed by all U.S. Services and be used by DoD as part of industrial base preparedness planning.

In summary, many studies have been performed that address foreign dependence. Several general conclusions can be drawn from these studies:

- foreign dependence is a national issue that is embedded in many U.S. industries;
- foreign dependence is not being addressed in any systematic or effective way;
- manufacturing technology (new processes and equipment) to reduce foreign dependency is not emphasized and is minimally supported by DoD;

- lack of action by DoD will result in increasing foreign dependence in future weapon systems; and

- solutions to foreign dependence must include both improved mobilization planning and acquisition contracting emphasis.

OFFICE OF TECHNOLOGY ASSESSMENT
HOLDING THE EDGE: MAINTAINING THE DEFENSE TECHNOLOGY BASE (MILITARY ACCESS TO CIVILIAN TECHNOLOGY)
April 1989

Background. This assessment was initiated by a concern on the part of Congress that the defense technology base may be eroding in the United States. As a result, the armed services might be unable to retain a technological advantage over the Soviet Union and other possible adversaries. This concern is related to two observations. First, certain high-technology industries such as semiconductors and numerically-controlled machine tools have lost domestic market share to foreign competition. Second, the U.S. military appears less and less able to acquire the leading-edge technology that does exist. Technology may be available in the civilian sector but not DoD.

Methodology. OTA conducted policy-oriented case studies of three dual-use technologies: fiber optics, software and advanced polymer matrix composites (PMCs). The purpose was to assess the availability of civilian technology for military purposes and to analyze difficulties in transitioning the technology between the civilian and military sectors of the U.S. economy. For each case, the inquiry addressed three central questions: (1) Are civilian high technology industries (those critical to the military) eroding in the United States? (2) Do military technologies and their applications diverge significantly from their counterparts in the civilian sector of the economy? (3) What are the principal barriers, both technical and institutional, that inhibit military access to civilian technology and vice versa?

Findings

1. Fiber Optics

a. Question 1: Technology Erosion

The U.S. fiber optics industry is strong today, but R&D is concentrated in two large companies, IT&T and AT&T. These companies face strong competition in the future, both from the European Communities (EC) and from Japan. The main findings that support this concern are:

- Current regulatory structure (separating telephone from television delivery systems) may retard the development of the optoelectronics industry in the United States. At the same time, EC and Japanese firms are gaining

experience in the production and commercialization of large-scale fiber optic local area networks in their home markets.

- The lack of international standards for fiber optic systems and associated optoelectronic devices may allow Japan and Europe to succeed in imposing standards on the competition in the future.

- Penetrating foreign markets is still difficult for American firms.

- EC and Japanese government have subsidized R&D in the optoelectronics field. In the U.S., government assistance is confined to military applications, and U.S. companies tend to pursue R&D independently.

- The U.S. continues to maintain a regime of export controls for fiber optics that is more restrictive than that of its CoCom partners. U.S. firms are excluded from participating in some markets that are open to European and Japanese concerns.

b. Question 2: Civil-Military Applications

In the fiber optics industry, the civilian sector is far in advance of the military in most areas. Optical sensors have enormous potential in a wide range of applications, both military and civilian. Many of the major sensors used by the military are analogous to those in the civilian sector.

c. Question 3: Barriers to Integration

The barriers that stand between the military and the commercial high-technology sectors are largely due to legal, institutional, and administrative factors, and are not inherent in the technologies themselves.

2. Software

a. Question 1: Technology Erosion

The U.S. software industry currently leads the world in both sales and technology leadership. However, the ability to meet the growing demand for software and the ability for the U.S. to maintain its dominance depends on the supply of computer programmers and technology available to them. Increasing competition from Japan, France, the United Kingdom, Korea and India may also impact the U.S. share of the market in the future.

b. Question 2: Civil-Military Applications

The software industry is increasingly divided into two areas, one that is dedicated to military systems and one that supplies the commercial world. Although both areas have analogous applications, military operating environments require more rigid requirements for custom-built software. Examples include 100 percent reliability for a missile guidance system or multi-level security in a networked defense communications system. The DoD mandate that Ada be the single high-order language in C#I and weapon systems further separates the military software industry from the commercial world. Civilian applications are implemented in the language considered best for the job.

c. Question 3: Barriers to Integration

No technical barriers are present that inhibit access to the technologies from either sector. Differences are due to how the government does business.

3. Polymer Matrix Composites (PMC)

a. Question 1: Technology Erosion

The United States leads the world in developing and using advanced PMC technology, based largely on the strength of its military aircraft and aerospace programs. The U.S. market is expected to grow faster than the world market in the next five years based on the military demand for PMCs.

Both domestic and foreign companies supply carbon fiber, a principal ingredient in PMC production. Since carbon fiber capacity worldwide is twice the current market volume no shortages are anticipated.

Foreign production of U.S. aircraft components is increasing and manufacturing of composites for commercial aircraft is moving offshore. This is an area to watch for possible future foreign dependence.

b. Question 2: Civil-Military Applications

Of all the technologies, advanced materials (PMC) shows the greatest divergence between military and civilian applications. There are significant differences in the molecular structure of each end-product because each PMC material must be individually designed.

c. Question 3: Barriers to Integration

No technical barriers exist between the military and commercial sectors. As in most technologies, access tends to be inhibited by the way each sector conducts business.

THE DEFENSE INDUSTRIAL AND TECHNOLOGY BASE FINAL RESULTS, 1988 DSB SUMMER STUDY December 1988

Background. The objective of the Task Force was to recommend a strategy and specific actions for the government and industry to adopt to ensure the defense industry can support U.S. national strategy objectives.

Methodology. The Task Force examined a broad array of data and discussed the issues with many experts from government, academia and industry. The DSB subgroup on Globalization addressed foreign dependency issues.

Summary. The subgroup found that globalization of U.S. defense markets has made the nation partially dependent upon foreign sources. Neither DoD nor industry currently has the means of measuring the scope of this dependence. Current acquisition policies and strategies do not sufficiently address this problem. The report discusses foreign dependency in critical technologies, components and spare parts for current defense equipment and systems, and a concern of the increase of foreign national students within U.S. graduate technical institutes coupled with the lack of interest of native Americans in pursuing science and engineering careers. Table 1 is a list of critical technologies the subgroup cited as areas where foreign dependency needs to be examined in terms of sourcing, dependence and vulnerability.

For defense systems and equipment, the subgroup recommended developing an 18-month supply of foreign vulnerability items. Studies should be conducted to assess the quantities and cost for the following:

- precision guided missiles;
- tactical aircraft ;
- armored vehicles;
- space assets; and
- C^3I assets.

The USD(A) should implement the procurement of the identified components and should test the efficiency of the system by selecting one area to test.

Table 1 CRITICAL "CATEGORIES" OF TECHNOLOGY	
Defense Emphasis	Industry Emphasis
Electro-Optics and Sensing Information Processing Micro Electronics Materials and Structures Energy and Propulsion Acquisition Process	Instrumentation and Communication Computing Equipment Semiconductor Materials and Processes Energy and Power Manufacturing Processes

In the area of education, the subgroup recommended that DoD take the lead in developing a national educational program to ensure long-term industrial base superiority. It should be a cooperative effort with the Department of Education and Commerce and should include:

- GI bill for technical education;
- secondary school incentives for ROTC; and
- 6.1, IR&D and Technology Base initiatives funds for graduate technical education.

AIR FORCE ASSOCIATION
LIFELINE IN DANGER: AN ASSESSMENT OF THE UNITED STATES DEFENSE INDUSTRIAL BASE (SEMICONDUCTOR INDUSTRY)
September 1988

Summary. This report concludes that, for a variety of reasons, the United States cannot have complete independence for its defense industrial base and should not try to achieve it. However, the U.S. should reduce its dependency on foreign suppliers for advanced semiconductors which are critical components for many military systems. Table 2 is a sample of U.S. military systems requiring semiconductors that are available only from foreign sources.

Table 2
WEAPON SYSTEMS UTILIZING FOREIGN SUPPLIED SEMICONDUCTORS

- Global Positioning System (Satellites)
- Integrated Underwater Surveillance System
- Defense Satellite Communications System
- SSQ AN-53B Sonobuoy
- F-16 Fighting Falcon
- AIM-7 Sparrow Air-to-Air Missile
- AM-6988 Poet Decoy (expendable jammer)
- Army Helicopter Improvement Program (OH-58 Kiowa)
- APG-63 Airborne Radar (for the F-15 Eagle)
- M1 Abrams Tank
- F/A-18 Hornet

Source: Defense Science Board Semiconductor Task Force, February 1987.

Reducing the U.S. dependency on foreign suppliers for semiconductors is not a small task. The U.S. is continuing to loose its leadership in world semiconductor technology to Japan. Table 3 depicts the shift in semiconductor technology.

Table 3
THE SHIFT IN SEMICONDUCTOR TECHNOLOGY

	Japan Lead	U.S.-Japan Parity	U.S. Lead
Silicon Products			
DRAMs	▼		
SRAMs	▼		
EPROMs		⬬	
Microprocessors			▼
Custom, Semicustom Logic			▼
Bipolar	▼		
Nonsilicon Products			
Memory	▼		
Logic	▼		
Linear			⬬
Optoelectronics	▼		
Heterostructures	▼		
Materials			
Silicon	▼		
Gallium Arsenide	▼		
Processing Equipment			
Optical Lithography		▼	
E-beam Lithography			
X-ray Lithography		▼	▼
Ion Implantation Technology			
Chemical Vapor Deposition		⬬	▼
Deposition, Diffusion, Other		⬬	
Energy-Assisted Processing	▼		
Assembly		⬬	
Packaging	▼		
Test	▼		
CAE		⬬	
CAM		▼	

▲ U.S. position improving.
⬬ U.S. position maintaining.
▼ U.S. position declining.

Source: Defense Science Board, Report of the Defense Science Board Task Force on Semiconductor Dependency (Washington, D.C.: Office of the Under Secretary of Defense for Acquisition, February 1987), p. 58.

In the silicon products market the Japanese have taken a dominant position in dynamic random access memories (DRAMs), a leading edge product of great importance to newer electronic products. These devices are now the proving ground for technology advances aimed at increasing chip density and decreasing cycle time (increasing computing speed).[1]

The Japanese also dominate the electronic materials market. Gallium arsenide (GaAs) is an important material in the semiconductor industry because it has a large, direct energy gap, high electron mobility, heterostructure capability with related materials, high temperature capability and a high degree of radiation resistance. Current military applications for this technology require the optoelectronic and microwave capabilities as well as the radiation resistance. Thus, supply problems exist for a number of critical military components.[2]

This U.S. loss of leadership in semiconductor technology is due in part to support given to Japanese companies by their government. The Ministry of International Trade and Industry (MITI) and Nippon Telephone and Telegraph (NT&T), both participate in joint programs with industry to develop advanced technologies and specified products. In order to combat these foreign government/industry joint ventures, the Congress and DoD, in conjunction with industry created the Semiconductor Manufacturing Technology (SEMATECH) initiative to ensure the U.S. of world-leading manufacturing capability with exclusively domestic content by 1993.[3]

In conclusion, the U.S. government and industry are just starting to address the foreign dependency issue for semiconductors. It is important that the nation maintains its interest in this problem if the U.S. hopes to regain leadership in the semiconductor industry.

1 National Research Council, "Foreign Production of Electronic Components and Army Systems Vulnerabilities," 1985, p. 23.

2 National Research Council, "Foreign Production of Electronic Components and Army Systems Vulnerabilities," p. 25.

3 SEMATECH Press Kit Paper: Meeting America's Technology Challenge, 1988, p. 2.

U.S. DEPARTMENT OF COMMERCE
INVESTMENT CASTINGS: A NATIONAL SECURITY ASSESSMENT
December 1987

Methodology. The assessment was initiated due to the critical position the industry occupies within the U.S. defense industrial base. The information in this study was compiled from responses to an industry survey, supplemented by a review of available literature and numerous contracts.

Technology. Investment castings are currently used in a variety of military and non-military applications. Table 4 summarizes U.S. defense purchases of investment castings between 1983-1985. Turbine blades and vanes, which dominate military purchases, are primarily used for gas turbines in airborne applications, although a growing number of ground and marine applications also apply.

Table 4
MILITARY/AEROSPACE QUALITY INVESTMENT CASTINGS

Product Area	Value ($ Millions)	Percentage
Turbine Blades and Vanes	$840,469,000	56.7%
Turbine, Other	131,481,000	8.9%
Missiles	115,302,000	7.8%
Aircraft-Airframes	67,819,000	4.6%
Aircraft, Other	66,985,000	4.5%
Tanks	65,462,000	4.4%
Electronics	64,139,000	4.3%
Weapons	18,213,000	1.2%
Automotive	536,000	
Other	112,190,000	7.6%
Total	$1,482,596,000	100.0%

Source: DOC/OIRA Industry Survey.

In general, the U.S. is a predominant exporter of investment castings. The top U.S. manufacturers of aerospace investment castings have a significant technological lead over foreign producers. However, as the technology diffuses to the European and Japanese foundry industries, the lead could diminish.

Dependence. The aerospace and military markets for investment castings require a high level of special alloys. The use of these alloys creates dependence on foreign production of investment castings. Table 5 summarizes import dependence information for nine essential metals used in the production of steel and/or aluminum and titanium alloys used in investment casting.

Table 5
SELECTED ALLOYING METALS USED IN INVESTMENT CASTINGS

Mineral	Import Penetration	U.S. Vulnerability to Foreign Disruption	Stockpiled	U.S. High-Grade Resource Adequacy to 1999
Manganese	100%	Yes	Yes	Insignificant
Tantalum	91%	Yes	Yes	Large
Chromium	82%	Yes	Yes	Small
Tungsten	62%	No	Yes	Small
Vanadium	54%	Yes	Yes	Small
Silicon	35%	No	Yes	None
Beryllium	16%	Yes	Yes	Insignificant
Lithium	**	Yes	No	Small
Molybdenum	**	Yes	No	Small

* 1984 level.
** Net explorer.

Source: Bureau of Mines.

Many of these metals are essential in imparting properties to an alloy without which performance would be substandard. A large number of these materials, such as manganese and chromium, are predominantly imported and either have no substitutes, or are substituted for only by other import-dependent metals. Most of these metals can be recovered from subeconomic domestic ore deposits, but the

cost in most cases is starkly prohibitive, and lack of technology or capacity makes short-term generation impractical.

Conclusions. The investment casting sector is dependent on foreign suppliers for numerous metals. Although this is not a problem during peacetime, according to U.S. foundries, in an emergency normal supply channels could be disturbed. Lead times for investment castings would grow.

Additionally, the U.S. has a limited production base of hollow-core blades and vanes and other highly sophisticated investment castings. Lead times for these products can be expected to rise to unacceptable levels in a surge or mobilization emergency.

A. INTEGRATED CIRCUITS (ICs)

Summary. The U.S. once was the world leader in integrated circuit (IC) production and technology. Today, Japanese products are eroding U.S. market share.

The U.S. world market share in ICs has declined from 76 percent in 1976 to 55 percent in 1986. In the same period, Japan's market share has increased from 16 percent to 36 percent.

U.S. IC producers' ranking among world firms has declined correspondingly. In 1976, eight of the top 10 firms were American compared to five in 1986. By 1992, only two US firms, IBM and Texas Instruments, are projected to be among the top 10 IC producers.[4] Six will be Japanese, one Korean, and one German.

The most obvious indication of Japanese market penetration has been in dynamic random access memories (DRAMs), for which there is a $4 billion worldwide market. In 17 years of participation (1970-1987), the Japanese have captured over 90 percent of the market.

The ascendancy of Japanese firms in markets has been accomplished by their relative improvement in technology. The CIA compared Japanese to United States technology in 20 cases and found that the Japanese were ahead in nine, at parity in eight, and behind in only three. In 14 cases, they were gaining on US firms; in no case were they falling behind.

Conclusions. The problems of the IC industry are fundamental to this country's ability to maintain its position as a high-technology producer. At present, the industry seems to be falling behind the Japanese in the development of many key production technologies. This may lead defense producers to depend more on overseas sources for their ICs.

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4 Integrated Circuit Engineering Corp.

Should that happen, difficult choices will have to be made to maintain access to leading edge technology in this area. One choice is to draw the Japanese firms into the military procurement orbit and use whatever leverage the United States has to allow domestic sources more access to Japanese technology. The other is to act to strengthen the competitive position of the domestic IC firms, a process best accomplished by increasing R&D in one form or another.

Whatever path is taken, it should be chosen in the context of a coherent strategy for the industry. This strategy should clearly identify the relationship between the industry's health and national security, the desired form of this industry, and the path that will take us from the present situation to the one desired.

B. MATERIALS SUPPLY AND DEMAND

Methodology. This study estimates supply and demand requirements for energy, metals, and minerals in a wartime scenario. The study ground rules assumed a four-year cutoff of imports from and exports to nations outside of North America, in the context of a major conventional war which absorbs $1.2 trillion (constant 1985) dollars from the U.S. economy. Additionally, North and South America may have some access to each other, but not to the Eastern Hemisphere.

Conclusions. This 1985 study showed that the United States could withstand an extended overseas oil cutoff without major impact on the economy. Use of excess capacity for production of both natural gas and electricity, coupled with likely shifts in demands in the economy, could compensate for reduced oil supplies. The collapse of oil prices in 1986, which caused a sharp fall in U.S. oil production and a decline in investment in energy conservation, has probably changed this situation. By the early 1990s, if oil prices continue to decline, it will become much more difficult to withstand an oil shortfall.

Some metals were found to be difficult to get in a war scenario. Table 6 lists these metals, indicating the early shortfall (first 18 months), the later shortfall (months 19-48), the size of the stockpile, and the net impacts of those factors. As shown in the table, beryllium, manganese, tin, and cobalt should not be a problem. Titanium could become a problem because the military is a heavy user. Problems in the supply of bauxite and alumina would develop if the U.S. were prevented from getting access to Jamaica and the southern Caribbean. Of the remaining metals, tantalum and columbium could present the worst problems. Both are used disproportionately in aerospace, and stocks of both are less than a year's worth of necessary imports.

Table 6
DEMAND VERSUS STOCKPILE FOR PROBLEM METALS[1]
(Data in Thousand Metric Tons of Contained Metals)

	Stockpile			
	Earlier	Later	Stockpile	Impact
Beryllium	.20	.35	1.2	$120M surplus
Manganese	900	600	1700	$50M surplus
Tin	58	48*	181	$1000M surplus
Cobalt	14	9	24	Adequate stocks
Titanium	33	–	24	12% shortfall thru month 18
Ferrochrome	180	–	550**	
Chromium Ore	610	940	650	75% shortfall after month 37
Tantalum	1.2	2.0	.9	80% shortfall after month 15
Bauxite	7000	12000	3600	90% shortfall after month 8
Columbium	4.5	7.2	.8	55% shortfall after month 3
Alumina***	2400	–	0	30% shortfall thru month 24

* Reflects reduction of 20,000 tons/year after month 18.
** Assumes the restart of ferrochromium plants currently idle.
*** Reflects 600,000 tons of revived capacity after six months and unlimited new capacity after 24 months.
1 Source is MCDC Study.

C. PRECISION GUIDED MUNITIONS (PGM) SECTOR

Methodology. If foreign-sourced components became unavailable during a war, production of the weapons which use them will be cut. To assess the seriousness of this situation, MCDC asked PGM prime contractors and their immediate suppliers to estimate the nature, reason, and length of this disruption. They were also asked what can be done to prevent it beforehand, and how much will these actions cost.

Dependency. Table 7 lists the PGM systems that have foreign-sourced components, impact to delivery schedule of the system if foreign sources were interrupted, and cost of buffering the PGM industry against a cut-off from overseas. The Table shows that items most critical to PGM production at current levels can be ensured for only $12 million. To meet surge schedules, an additional sum of only $2.7 million is required.

Table 7
MITIGATION COSTS BY AFFECTED COMPONENT[1] ($K)

Item	System	Source	Impact	Buffer Stocks FYDP	Buffer Stocks Surge
Silicon FET	Radar	Japan	12+ mo (all)	1500	1000
Ferrite Cores	Radar	Germany	12+ mo (all)	150	100
Rocket Mtr Case	Skipper	U.K.	9 mo (all)	1600	200
Rocket Mtr Case	HARM	U.K.	7 mo (60%)	**4800	1000
Rocket Mtr Case	Harpoon	U.K., Australia	7 mo (all)	600	0
GaAs FET	Radar	Japan	6+ mo (all)	200	100
Butane Triol	***	Germany	6 + mo (all)	600	50
Sapphire	Sdwr et al.	Switzerland	6 mo (all)	100	50
Copper Preform	Copperhead	Switzerland	6- mo (all)	250	50
PWB Plating	HARM	U.K.	6- mo (all)	50	20
Springs, Pivots	Phoenix	Germany, So. Af	6- mo (all)	1	0
Ball Screws	Patriot	U.K.	3 mo (all)	30	10
Precision Optics	****	Japan, Germany	3 mo (all)	250	50
Actuator Mtr	HARM	U.K.	3 mo (75%)	1100	0
Gear Mtr	HARM	U.K.	3 mo (50%)	100	0
Castings	Standard	Israel	3 mo (50%)	50	0
Radome Chemicals	Radar	Mexico	3- mo (all)	50	0
Molybdenum Foil	Patriot	Austria	2 mo (all)	2	0
Launch Tube	Stinger	Israel	2 mo (75%)	100	0
Extrusions	Harpoon	Australia	2 mo (50%)	300	0
Bearings	Standard	Overseas	2- mo (all)	10	0
Integrated Circuit Pts	All	East Asia	Varies	200	50
Total				12043	2680

* Additional stocks needed to hit 150 percent of rate in nine months.
** Includes $800,000 in additional tooling.
*** Standard, Patriot, Maverick, Sidewinder et al.
**** Sidewinder, Maverick, HARM et al.
1 Source is MCDC Study.

Conclusions. Not all dependencies are vulnerabilities. An assessment of the latter would be heavily influenced by the sources involved and the chances the U.S. would be cut off from them. Most of the foreign sources are allies or friendly neutral countries. Except at the materials level, no third-world country is represented.

Other Data Sources. The U.S. Air Force 1985 Production Base Analysis and the JCS study Precision Guided Munitions, Phase I and II, 1985 found the foreign dependencies indicated in Table 7.

MACHINERY AND ALLIED PRODUCTS INSTITUTE (MAPI) SURVEY ON GLOBAL SOURCING AS A CORPORATE STRATEGY August 1987

Summary. The purpose of this survey was to determine the use of global sourcing as a worldwide corporate strategy. The survey sample included 171 companies producing a broad range of products in the manufacturing industries. Based on 107 responses (63 percent return), and results of two earlier surveys (1984, 1985), the following conclusions were made.

The primary objectives for sourcing on a global basis continue to be lower cost and improved quality. The most important risks are considered to be length of supply lines, currency fluctuations and inventory levels. New data and responses to additional questions indicate that:

- foreign purchases as a percentage of domestic purchases reached a new high in 1985, averaging 15.5 percent;
- eighty-six percent of the respondents expect the importance of global sourcing as a percentage of their total purchases to continue to grow over the next decade; and
- the rate of growth of foreign sourcing, however, may have peaked, as roughly 50 percent of the survey respondents returned home to source some purchases.

To offset the risks of global sourcing two-fifths of respondents have engaged in a joint venture to serve as a foreign source of supply for the U.S. market. Additionally, two-fifths of respondents have shifted sources from one foreign country to another in the last year because of currency fluctuations and reliability of supply.

JOINT LOGISTICS COMMANDERS
PRECISION OPTICS STUDY
June 1987

Methodology. As part of this effort, the Department of Commerce, Office of Industrial Resource Administration, surveyed the U.S. Precision Optics and Optical Material producers. Plant visits were also conducted by the study team to enhance survey questionnaire data.

Foreign Depencence. Most optical companies are reliant on imports, according to survey results. Overall, firms use an average of 32 percent imported optical and filter glass in their production, while 41 percent of infrared material is imported. The primary foreign suppliers of optical glass are Japan and West Germany. Infrared raw materials are imported primarily from Europe (France, West Germany, and Belgium). The reasons given for importing are price and lack of adequate domestic sources.

Machinery, equipment, and tools used in optics production are also items being produced offshore. The main sources for these items are Japan, West Germany, and England. Inadequate domestic supply and better quality are the main reasons for importing equipment.

Conclusions. The domestic optical industry has declined drastically in recent years because of foreign competition. The resulting deterioration in surge and mobilization capabilities can threaten our national security.

To offset this trend, the study group recommended the implementation of a FAR clause to stop the incursion of foreign producers into the defense market, encourage domestic capital investment and provide incentives for technology development. The services should place more emphasis on technology programs that foster optical fabrication advancement, and an assessment of trade and economic factors impacting the optics industry should be initiated.

REPORT OF THE DEFENSE SCIENCE BOARD TASK FORCE ON DEFENSE SEMICONDUCTOR DEPENDENCY
February 1987

Background. The objective of this Task Force was to assess the current semiconductor industry and identify causes of its loss of technological leadership. To lessen the harmful effects on national security that are threatened by this loss, a joint Department of Defense/Industry initiative comprising research, educational, production, and administrative elements to address the most pressing needs in semiconductor technology, was proposed.

Summary. The Task Force concluded that procurement by the Department of Defense is a relatively insignificant factor to the semiconductor industry; but, in contrast, the existence of a healthy U.S. semiconductor industry is critical to the national defense. Because of this asymmetry, the Task Force believed that it is imperative for the Department of Defense to take action to assure the long-term viability of a U.S. semiconductor industry which can at least meet critical defense needs. Semiconductors today represent the most highly leveraged and most ubiquitous element for assuring the technological superiority of the United States' military forces.

Continued availability to the Department of Defense of the most technologically advanced products will be dependent upon the maintenance of a domestic leading edge technology development and production base capable of timely supply of defense needs. This availability is by no means assured. The U.S. will depend to a large degree upon foreign sources of microelectronics hardware and technology to meet its defense needs unless measures are taken to help this country recapture and maintain leadership in semiconductor manufacturing technology. Action therefore must be taken to retain and gain adequate technological leadership in the U.S.

Recommendations. The task force's recommendations were:

1. Support the establishment of a Semiconductor Manufacturing Technology Institute.

2. Establish at eight universities Centers of Excellence for Semiconductor Science and Engineering; built upon current NSF, DoD, and commercial consortium programs.

3. Increase DoD spending for research and development in semiconductor materials, devices, and manufacturing infrastructure.

4. Provide a source of discretionary funds to the Defense Department's semiconductor suppliers.

5. Establish under the Department of Defense a Government/Industry/University forum on semiconductors.

USAF/AIM
GAS TURBINE ENGINE (GTE) PRODUCTION BASE ANALYSIS STUDY
February 1987

Methodology. The GTE primes and their subcontractors were surveyed via a comprehensive questionnaire to determine the capability to surge and/or mobilize under crisis conditions. Data on GTEs used in the air, on land, and at sea were all included. The baseline for this study consisted of the FY1984, CY1985, and CY1986 Production Base Analysis reports.

Dependence. During a peacetime scenario, several foreign dependencies were identified. Approximately 5 percent of GTE critical parts were foreign sourced; however, none are sole sourced. Foreign ownership of high technology subcontractors is increasing. The primes have contingency plans for accommodating a sudden disruption in the supply of foreign sourced parts, but subcontractors do not have plans. The primes reported that in 41 percent of the cases where manufacturing equipment was purchased overseas, spare parts were available only from that source. Foreign dependency is increasing for machine tools, machine tool parts and strategic/critical materials.

During a mobilization scenario, the primes expressed a concern about the availability of domestic sources for production equipment.

Conclusions. Foreign dependency of GTE parts is increasing but is currently under control. The major concern is the increased use of foreign production equipment in the manufacture of GTEs. Resources should be made available to develop domestic sources for critical production equipment.

JOINT LOGISTICS COMMANDERS
BEARING STUDY
June 1986

Methodology. The study was initiated in response to Congressional concerns over the availability of bearings in an emergency and the use of foreign manufactured bearings in U.S. weapon systems. In performing this assessment data was collected from the Services and Industry, visits to industry plants were conducted, and previous bearing Industry studies were evaluated.

Dependence. Foreign bearings and components are increasingly being used in DoD weapon systems. This trend is a result of increasing lead times and higher prices for domestic bearings. From 1981 to 1984, the Navy was 100 percent dependent on a Japanese source for noise quiet superprecision bearings. In 1984, the Navy initiated an effort to develop domestic sources. Two years of effort resulted in only one qualified producer.

The original equipment manufacturers (OEMs) indicated that they will continue to qualify and use more foreign bearings in their newly designed systems. This includes superprecision bearings for critical military applications. The increasing dependence of DoD weapon systems on foreign-produced bearings will ultimately weaken the U.S. industrial base.

Surge and mobilization production capabilities for superprecision bearings by U.S. firms are not good. Overall, 40 percent of firms surveyed would not be able to meet surge targets and 50 percent would not be able to meet mobilization targets.

Impact/Conclusions. The use of foreign bearings in weapon systems can have serious implications when determining readiness and sustainability for surge and mobilization. During these scenarios, any disruption in supplies of imported bearings would result in long procurement lead times and create shortages that could shut down production lines and/or limit the operation of critical weapon systems. Recent bearing shortages have caused grounding of our first line aircraft and line stoppage of M-1 tank production.

When foreign sources are cut off, U.S. companies would be expected to produce bearings at an accelerated rate. These companies may not be able to support the sudden increase of requirements due to a lack of capacity/capability.

JOINT LOGISTICS COMMANDERS
A STUDY OF THE EFFECT OF FOREIGN DEPENDENCY
February 1986

Methodology. After completion of a data gathering activity by interviewing a wide range of officials from Federal agencies, trade associations, military procurement and planning organizations and defense manufacturers, seven military systems were selected for detailed analysis. The systems were the F-16 and F-18 aircraft, Advanced Helicopter Improvement Program (AHIP), M1 Tank, AIM-7M Sparrow, Combined Effects Munitions (CEM), and Sonobuoys. The subsequent investigation extended into the lower subcontractor/vendor levels. For each system, subassemblies, components, parts, and materials were examined for foreign dependency.

Midway through the project, six additional weapon systems were examined to substantiate conclusions beginning to develop. Since the initial list emphasized complex systems, the second list concentrated on less-than-major programs. These systems were the 5-ton truck, improved conventional munitions, the AV-8B Harrier Aircraft, the AR-5 aircrew chemical protective suit, the AN/ALQ-131 electronic countermeasures pod and the 25K and 40K loaders for cargo aircraft.

Dependence. Table 8 highlights the systems that were discovered to have major foreign dependencies. As shown in the table, foreign dependency exists in four of the original seven weapon systems studied. Several of these items are considered mid-to-high technology major subsystems. Examples include the heads-up display for the F-16, the ejection seat for the F-18 and a cryogenic cooler for the AHIP. These identified dependencies, with a few important exceptions, are from NATO allies and Japan. The principal exception is dependency on U.S. manufacturers who take advantage of low cost labor in the Far East.

Conclusions. The U.S. is vulnerable to foreign dependency during peacetime. If foreign sources of supply are cut off, U.S. production of certain components will drop to zero for months or even years. This conclusion was reached independently of other mobilization production problems.

Table 8
WEAPON SYSTEMS WITH FOREIGN DEPENDENCIES

System	Item	Source
Sparrow	Electronics Japan Raw materials Chemical products	Various countries Federal Republic of Germany
M-1 Tank	Microelectronics Extrusions Optic glass	Japan United Kingdom FRG, Japan
AHIP	Ceramic packages Micro circuits Cryogenic cooler	Japan FRG/Japan
F-18	Ejection seat Magnetic resistors Ceramic packages	U.K. FRG Japan
Sonobuoy	Microprocessors	Japan
F-16	Ceramic packages Heads-up display	Japan U.K.
AR-5 (Chemical protective suit)	Entire system	U.K.
AV-8B Aircraft	Joint venture with British Aerospace and McDonnell Douglas	Joint venture with British Aerospace and McDonnell Douglas

U.S. AIR FORCE
PRODUCTION BASE ANALYSIS, SPACE SECTOR
1985

Summary. In the Space Sector Report, two supporting technologies were found to be foreign dependent. They are precision instrument bearings used in space applications and beryllium material used in the manufacture of spaceborne optical components.

Precision instrument bearings for space applications are no longer available from some manufacturers and not standardized because each buy is a custom order. Further, bearing sources are in jeopardy due to foreign acquisition of domestic suppliers and the potential dropping of low volume lines.

Beryllium is now available from only one domestic manufacturer. This has impacted suppliers of spaceborne optical components. The scope of this finding and the specific impact on space applications was not identified during the 1985 production base process (PBA) process. However, it appears that critical materials availability should be identified as an industrial capability PBA process issue.

Recommendations. For the precision instrument bearing technology, the study team recommended developing a supplier production database, analyzing the extent of foreign dependency and developing an action plan to reduce this dependency.

In the materials area, it was recommended to determine the full impact of beryllium foreign dependency on suppliers of spaceborne optical components. Additionally, materials availability was identified as a future PBA process manufacturing management issue.

U.S. AIR FORCE
PRODUCTION BASE ANALYSIS, ELECTRONICS SECTOR
1985

Summary. The movement of IC production to overseas is well documented. Data reveals that more than 90 percent of military ICs are manufactured overseas. Most military packaging for ICs are produced in Japan. Lead times for procuring ceramic packages are averaging 20 weeks. Polycrystalline silicon, an essential material used in IC production, also is primarily manufactured overseas.

Based on these facts, the study team concluded that foreign dependence in IC production would be a major impediment to a successful surge. Other problems identified in the U.S. industry's ability to meet IC surge capacity include the high cost and long lead time of test equipment, the labor intensive IC inspection process, extensive government documentation requirements on the manufacturer, and the IC manufacturer's lack of surge forecasting ability.

The study team made several recommendations to improve the manufacturing capability of integrated circuits and improve the U.S. surge scenario. These include: increasing the use of automation in manufacturing; utilizing homogeneous integrated circuits, that have a commercial market, for military systems; producing critical sub-components domestically; and focusing Industrial Modernization Incentives Program (IMIP) and Manufacturing Technology (MANTECH) Programs at the IC vendor level instead of the prime contractor level.

INDUSTRIAL RESPONSIVENESS ANALYSIS (IRA) STUDY
May 1985

Background. IRA was a mobilization effort tied to the next major Joint Chiefs of Staff mobilization exercise, PORT CALL 86. Its purpose was to assess industry's true capability to support military materiel demands in a mobilization environment, to identify constraints to meeting materiel demands, and to identify actions Government could initiate to optimize production. The IRA Study was a follow-on to several studies:

- JCS Precision Guided Munitions (1984/1985);
- AF Blueprint for Tomorrow (1983);
- Industrial Responsiveness Simulation (1983);
- Proud Saber (1982);
- REX 82 Bravo (1982);
- Proud Spirit (1980); and
- Nifty Nugget (1978).

Thirty-one critical items were chosen by the military services for study. Twenty-four defense contractors participated. Reports on each item were analyzed by the American Defense Preparedness Association and industry representatives.

Dependence. The F-15 APG-63 Radar System, the AN/PRC-119 Sincgars Radio, Electronic Systems, and Electronic Test Equipment were shown to rely heavily on foreign sourced parts. Some of these systems rely on a single foreign source for unique parts and processes. In addition to foreign sourced parts, defense contractors for the M-1 Tank and the M16A2 Rifle Systems are concerned with the domestic machine tool industry. Many U.S. contractors rely on foreign supplied production equipment to manufacture weapon systems.

Survey results also indicate that the U.S. semiconductor industry has moved offshore resulting in a very limited surge capability. Wafer crystals, critical to the electronics industry, are being supplied by Japan, Israel, Germany, and Taiwan.

Conclusions. The U.S. capability to support military materiel requirements is diminishing. A foreign source cut-off in components and production equipment would delay production of the systems analyzed in this report.

GENERAL ACCOUNTING OFFICE
ASSESSING PRODUCTION CAPABILITIES AND CONSTRAINTS IN THE DEFENSE INDUSTRIAL BASE
April 1985

Methodology. The GAO examined data on production delays, inferior quality and cost increases in the defense industrial base (DIB) for six weapon systems. The systems analyzed were the AIM-54 Phoenix missile, the M1-Abrams tank, the TOW2 missile, the HARPOON missile, the F100 turbofan engine, and the Global Positioning System.

Dependence. All weapon systems analyzed rely on some materials and components acquired from foreign sources. Many system components use some type of material having an import dependency of 50 percent or more. Examples of major components from foreign sources are shown in Table 9.

Table 9
SYSTEM FOREIGN DEPENDENCIES

System	Components	Source
TOW2	Quartz optics	
M1	Circuit board assemblies hybrids	Mexico Taiwan
HARPOON	Radar seeker	Germany/U.K.
F100	Engine bearings	Germany

Contractors also expressed concern about the level of dependence of foreign suppliers for semiconductor and microelectronic parts. It is estimated that 80 to 90 percent of military semiconductors are assembled and tested outside the U.S., but the exact level is unknown. This study was not able to address this issue in depth.

Conclusions. Most current and potential production restraints for weapon systems occur at the subcontractor level. Therefore, a better understanding of subcontractor production requirements would be improved by systematic data collec-

tion and analysis. Data to be collected should include foreign sources of components and raw materials, plant capacity, scrap and rework, and proprietary production processes. This information should be contained in a weapon system database for access by all Services.

OFFICE OF TECHNOLOGY ASSESSMENT
INTERNATIONAL COMPETITIVENESS IN ELECTRONICS: OFFSHORE MANUFACTURING
November 1983

Summary. Virtually all major U.S. owned consumer electronics and semiconductor companies have offshore plants, mostly in Mexico and the Far East. American electronics firms establish offshore manufacturing facilities to take advantage of low-cost foreign labor. Investing companies see cost reductions as critical for meeting competitive threats from foreign enterprises, or to expand output and sales in competition with other domestic firms, or both.

If offshore manufacturing is eliminated by Government policy, four alternatives are available to American firms. The choices are:

- maintain production in the United States, using labor-intensive processes similar to those that have been followed in offshore plants;
- maintain production in the United States, investing in automated equipment;
- subcontract production to an independent foreign manufacturer; and
- discontinue production and sales of the product or products in question.

Of the four options, U.S. consumer electronics firms would probably adopt a mix of the first three, depending on their product lines and competitive circumstances. In particular, the smaller consumer electronics manufacturers are much more limited in investment possibilities (that is, in automation) than companies like GE or RCA. In the semiconductor industry, the cost savings from offshore production are so large (Table 10) that most American merchant firms would no doubt subcontract to foreign enterprises if they could not invest overseas themselves. Some production would be transferred back to the United States, probably high-volume products made by larger companies.

Table 10
COST COMPARISON FOR OFFSHORE ASSEMBLY OF SEMICONDUCTORS*

	Discrete Devices or Simple Integrated Circuits			Large-Scale Integrated Circuits		
	Offshore Assembly	Domestic Assembly Wage Ratio**		Offshore Assembly	Domestic Assembly Wage Ratio**	
		10:1	5:1		10:1	5:1
Cost of chip	$0.015	$0.015	$0.015	$1.00	$1.00	$1.00
Assembly cost	0.050	0.500	0.250	0.15	1.50	0.75
Packaging cost	0.050	0.050	0.050	0.50	0.50	0.50
Testing cost	0.020	0.020	0.020	0.75	0.75	0.75
Reject cost	0.015	0.015	0.015	1.00	1.00	1.00
Total	$0.150	$0.600	$0.350	$3.40	$4.75	$4.00

* The basic costs used in this table are from *A Report on the U.S. Semiconductor Industry* (Washington, D.C.; Department of Commerce, September 1979), p. 73. These costs do not apply to specific devices, nor are they necessarily current. The purpose is simply to illustrate the magnitude of the cost savings available through off-shore assembly.

** Assumed ratio of U.S. wages to wages in offshore plant.

Source: "Effects of Offshore and Onshore Foreign Direct Investment in Electronics: A Survey," prepared for OTA by R. W. Moxon under Contract No. 033-1400, p. 20.

In general, the advantages and disadvantages of offshore manufacturing versus domestic manufacturing can only be evaluated on a case-by-case basis. In this study, the net impacts of offshore manufacturing to the U.S. economy, by U.S. electronics firms, appear to be small. On the other hand, policies that would restrict overseas investments by U.S. firms seem counterproductive.

INDUSTRIAL COLLEGE OF THE ARMED FORCES
U.S. DEPENDENCY ON FOREIGN SOURCES FOR COMPONENTS: THE CASE OF SEMICONDUCTORS
March 1983

Methodology. The paper investigates the foreign dependency on semiconductor products and the potential impact it may have on military mobilization. Authors investigated previous reports and efforts discussing the foreign dependency issue including:

- 1977 Defense Electronics Supply Center Report ;
- 1980 Congressional Report;
- 1981 Defense Science Board Report; and
- 1982 JLC *ad hoc* Group.

Summary. The paper concluded that the U.S. semiconductor industry is threatened by competition from abroad, some of which is subsidized by foreign governments. U.S. military systems are becoming increasingly dependent on semiconductors processed offshore. An analysis of four different tactical systems to determine foreign dependency (assembly and testing) found that offshore dependency ranged from 17 to 33 percent.[5] There is no formal established system to track the amount of foreign dependency for semiconductors to determine if a problem may arise for need during mobilization.

The authors recommend that DoD should establish a system for highlighting foreign dependency vulnerability data and use it within the industrial preparedness planning process. Additionally, DoD should establish requirements for identifying foreign dependencies associated with semiconductors in the development and procurement of new systems.

5 Interview with Mr. Gene McAllister, Magnavox Co., February 1983.

APPENDIX C
CONTRIBUTORS

Three contractor teams made this report possible: Erland Heginbotham (project manager), Harold E. Bertrand, Herbert Brown, John McHale, Joseph M. Ruzzi, Peter B. Almquist, George Sorkin, and Stephen N. Wooley from the Institute for Defense Analyses; Lois Lembo (project manager), Jacques Gansler, David Leech, Don Dobeasky, Carol Neckyfarow, and Leon Reed from The Analytical Sciences Corporation; and Bob Davidson from Science Applications International Corporation. Louisa Koch, a Presidential Management Intern on loan to DARPA, also made important contributions.

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